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NOISE CONTROL IN UNDERGROUND MINING

M J Howes

Camborne School of Mines

INTRODUCTION

The equipment used in the mining processes of breaking and removing rock and the provision of essential services such as ventilation are inherently noisy. This is primarily associated with large amounts of energy required during these processes. Although residential acceptance criteria and speech or signal interference are occasionally necessary for a given installation, hearing conservation is the normal design criteria applied for noise control in mines.

The major noise sources are mine fans, rock drills and diesel powered equipment with sound power levels between 110 and 130 dB. Within the constraints of underground excavations bounded by rigid rock surfaces, the exposure levels of miners range from 100 to 120 dB(A) for a major potion of the working shift. Methods of reducing noise levels are discussed along with their limitations in the practical mining environment. Areas of further work which will result in more consistent and reliable control measures are identified.

MAIN SOURCES OF NOISE IN MINES(1,2,3,4,5)

Mine Fans

Main mine fans are usually located on surface. An installation may comprise of one, two or three fans in parallel with a typical total absorbed power of 1000 kW although this may range between 100 and 10 000 kW. Fan static pressures are moderate to high, typically 2.5 kPa and generally range between 1 and 10 kPa.

Both axial flow and centrifugal fans with backward inclined blades are used depending on the static pressure requirements and the application. Centrifugal fans are normally used where the static pressure exceeds 5 kPa and where unusually arduous conditions exist such as a large water carry over from the exhaust shaft. Where the fans are located on surface, noise control may be related to residential acceptance.

Underground booster and auxiliary fans are almost exclusively electric motor driven, medium pressure axial flow fans operating with static pressures of between 1.5 and 2.5 kPa. The sizes range from 600 to 1500 mm in diameter requiring input powers of between 10 and 100 kW. A reasonable estimate of the overall sound power level between 63 and 8000 Hz for this type of fan can be obtained from the following relationship:-

$$SWL = 100 + 10 \log (QP^2) \text{ dB}$$

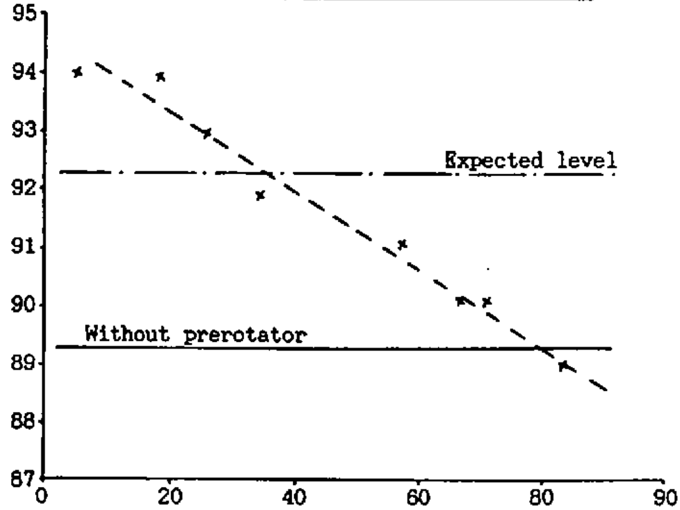
where SWL = the fan sound power level (dB)
Q = the fan delivery quantity (m^3/s)
P = the fan total pressure (kPa)

Corrections to obtain the octave band spectra of mine axial flow fans

Mid-band frequency Hz	63	125	250	500	1000	2000	4000	8000
Correction dB	-7	-9	-7	-7	-8	-11	-16	-18

The overall sound power levels of auxiliary fans typically varies between 110 and 130 dB. To achieve the required performance the axial flow fans usually require either a prerotator or stators after the rotor. Prerotators can significantly increase the noise levels of a fan depending on the distance between the prerotator blades and the rotor blades. Figure 1 illustrates the overall sound power levels of a 380 mm diameter fan supplying 1.3 m^3/s at a static pressure of 300 Pa with an increasing gap between the prerotator and the rotor.

Figure 1 - Effect of prerotator spacing



Rock drills

There are over ten sources of noise in a rock drill which can be separated into three main components. In a pneumatic rock drill the main source of noise is the cyclic release of the exhaust compressed air as a high velocity jet into the comparatively still surrounding air. At the boundary of the jet and the air at rest there is a turbulent mixing region with very high shear flows and very intense pressure fluctuations.

The frequency spectrum is broad, having a peak between 250 and 1000 Hz, but being significant in the 125 to 2000 Hz frequencies. The exhaust contributes between 85 and 90% of the total sound power from an unmuffled pneumatic drill. An estimate of the overall sound power level between 63 and 8000 Hz of such a drill can be obtained from the following relationship:-

$$SWL = 140 + 10 \log Q \ \text{dB}$$

where SWL = the sound power level (dB)
Q = the free air consumption (m^3/s)

Corrections to obtain the octave band spectra of pneumatic rock drills

Mid-band frequency Hz	63	125	250	500	1000	2000	4000	8000
Correction dB	-20	-12	-5	-5	-10	-12	-13	-15

A typical pneumatic drill uses between 0.06 and 0.10 m^3/s of compressed air resulting in overall sound power levels of 128 to 130 dB. The second major source of noise is that radiating from the drill steel. Hand held drills (drilling assisted with airlegs) use drill steels between 1.2 and 2.4 m long whereas the cradle mounted drills used in drill jumbos use drill steels between 3 and 4.5 m long.

Approximately 80% of the energy imparted by the piston to the drill steel is useful in the drilling process with the balance usually ending up a bending waves in the drill steel. The noise radiating out from the drill steel depends on many factors such as the thrust applied, the assembly and alignment of the drill steel shank in the chuck and whether or not the bit is an integral part of the drill steel. Higher noise levels (2 to 3 dB) occur when the drill steel is most exposed particularly when collaring and the drill is muffled.

The third source of noise is that radiating from the body of the rock drill. Sources of noise within the rock drill casing are numerous and are normally the result of impacts such as the piston on the shank of the drill steel and the cylinder walls, valves on valve seats and the chuck on the chuck housing. The noise from the body of the rock drill is approximately 30 to 50% of that from the drill steel and only becomes significant when the rock drill is muffled.

Hydraulic rock drills do not have the exhaust noise and the overall sound level is between 5 and 8 dB lower than the equivalent pneumatic rock drill. The frequency spectrum is similar with a slightly larger correction in the low frequencies and a smaller correction in the high frequencies.

Miscellaneous equipment

Other equipment producing noise that may be encountered in mining include motors, drives, pumps, rock cutting machines, crushers, mills and diesel engines. When considering diesel powered equipment there are several noise sources which can be broadly classified into exhaust noise and engine noise. All diesel equipment used underground has some form of gas scrubber/silencer which normally reduces exhaust noise to below the engine noise level. An estimate of the sound power level of diesel engines below 300 kW in size can be obtained from:-

$$SWL = 100 + 8 \log kW \ \text{dB}$$

where SWL = the sound power level (dB)
kW = the rated power of the diesel engine

NOISE CONTROL IN UNDERGROUND MINING

The service vehicles used in underground mines for personnel and equipment transport have diesel powered engines between 50 and 100 kW. For ore extraction and short hauls (normally less than 150 m), load-haul-dump equipment with capacities between 6 and 15 tonnes are used which are equiped with diesel engines between 150 and 250 kW in size. Underground trucks are used to haul rock up to several 1000 m and range in capacity from 12 to 50 tonnes. They have diesel engines with outputs of between 100 and 350 kW. The overall sound power of this diesel powered equipment will vary between 115 and 120 dB.

One interesting feature of the diesel powered equipment is the contribution to the overall level provided by the low frequencies (63 Hz and less). Acceptable equivalent continuous sound levels are normally given in terms of dB(A). Weighting networks were developed to allow for the response of the ear to both frequency and sound level with the A-scale suitable for sound pressure levels up to 55 dB, the B-scale between 55 and 85 dB and the C-scale for over 85 dB.

The use of the A-scale weighting network is therefore in conflict with hearing conservation work. The almost universal use of the A weighting probably stems from the desire to simplify noise measurement particularly when taking into account exposure factors. It was presumably felt that any error involved in the simplification would be within normal measurement tolerances.

Subsequent work (6) has indicated that the B-weighting more nearly equates with hearing losses than does the A, and that no weighting overcompensates. A logical but unsubstantiated conclusion would be that since C-weighting lies between B-weighting and no weighting it would be more appropriate and would confirm the original purpose of the C-weighting network.

In mining, the frequency spectra tend to fall i.e. the mean of the sound levels in the 2000 and 4000 Hz octave bands are lower than the mean of the sound levels in the 250 and 500 Hz octave bands. Use of the A-scale weighting network will therefore normally result in an underestimate of the damaging effects of noise. For fans and rock drills this is of the order of 2 or 3 dB which, although a significant difference, is not excessive when considering measurement tolerances. This is not the case when considering the operation of diesel powered equipment where the difference between the A and C weighted overall levels is between 12 and 15 dB. This results from the high sound levels in the low frequencies and the large A-scale adjustment in these frequencies.

THE PATH AND CONTROL

Underground Excavations

When underground, any sound source is constrained by the rock surfaces of the excavation. In hearing conservation work, in order to estimate the sound pressure level, it is necessary to use the sound power of the equipment and the geometry of the excavation. In large underground openings such as pump stations, hoist rooms and crusher stations, sound transmission by the air path can be subdivided into direct and reflected components. These rooms are typically 10 to 15 m wide, 10 to 15 m high and 25 to 50 m long. Standard methods can be used to determine both the direct and reflected components providing that the absorption coefficients for the rock surfaces are known.

NOISE CONTROL IN UNDERGROUND MINING

Most underground excavations are drifts and haulages with cross sectional areas between 6 and 30 m^2 and lengths of several hundred metres. When estimating sound pressure levels at distances in excess of the excavation width from the source, absorption of sound by the rock surfaces is increasingly important. The attenuation of sound levels with distance from the source resulting from absorption by the rock surfaces can be estimated from the following relationship:-

$$dB = 12.6 \frac{P}{A} x^{0.6} \alpha^{1.4}$$

where dB = the sound reduction over x m in dB

$\frac{P}{A}$ = the ratio of perimeter to cross sectional area of the excavation

x = the distance from the source

α = the abosorption coefficient

Values of the absorption coefficient α for rock surfaces at different frequencies are given in the following table. These are based on tests in airways surrounded by a basalt rock. Subsequent tests undertaken in an airway driven in granite gave very similar results. More recent measurements taken in a shaly rock known as killas resulted in absorption coefficients some 20 to 30% higher. In all cases the absorption coefficients are significantly higher than those given for concrete and are probably a result of dust on the rock surface, a much greater surface area caused by surface irregularities and the porosity of the footwall aggregate.

Absorption coefficients of rock surfaces in underground excavations

Mid-band frequency Hz	63	125	250	500	1000	2000	4000	8000
Absorption coefficient	0.05	0.10	0.13	0.14	0.15	0.16	0.16	0.16

In all cases it was difficult to determine the absorption coefficient at low frequencies. The frequency at which half the wave length was equal to the drift width varied between 40 and 70 Hz. This is the frequency resulting in the maximum attenuation at a discontinuity in the airway. The drill and blast method of driving most airways results irregularities averaging 0.25 m in height and cross sectional area differences of up to 25%.

Fans

Main fans, when situated on surface, are usually located well away from residential and office areas and do not require any special attenuation. Where this is not possible, extensive work is required with a commensurate increase in cost. In one example where a fan was to be replaced in a residential area with houses within 50 m of the installation, the overall cost of the installation increased to five times the cost of the fans alone. The inlet drift to the fan was designed to minimise noise breakout with concrete block cavity walls and a large split absorption silencer was installed at the fan discharge.

Auxiliary fans used underground are usually associated with duct systems which normally provide sufficient attenuation at the discharge of the fan. Both steel and flexible ducts are used. Fexible ducts have attenuation values between two and four times those of steel ducts with inceasing attenuation at the higher frequencies. The noise breakout is, however, two to three times lower in the middle frequencies i.e. the reduction in sound pressure level at 1000 Hz between the inside of a 760 mm diameter duct and 1 m away from the duct is 23 dB for a steel duct and 10 dB for a flexible duct. The following table compare the attenuation and breakout values for 760 mm diameter steel and flexible ducts.

Attenuation in dB/m of 760 mm diameter ducts

Mid-band frequency Hz	63	125	250	500	1000	2000	4000	8000
Steel ducts	0.08	0.13	0.17	0.21	0.25	0.28	0.30	0.31
Flexible ducts	0.15	0.25	0.55	0.75	0.95	1.05	1.15	1.25

Reduction in SPL between inside and outside of the duct (1 m from duct)

Mid-band frequency Hz	63	125	250	500	1000	2000	4000	8000
Steel ducts	30	18	28	32	23	22	27	29
Flexible ducts	23	11	8	7	10	16	21	22

When considering hearing conservation, an absorption silencer is usually necessary at the fan inlet. In one example a 1.2 m diameter fan with a 90 kW motor required a 2.4 m long silencer with a centre pod. This effectively doubled the mass of the fan installation. (A 1.2 m long straight silencer was also required at the fan discharge to meet the design criteria). An additional problem is the aggressive environment in which the equipment must operate where silencer effectiveness decreases with time and the absorption material requires frequent replacement. The increased pressure loss resulting from using the silencer can add up to 5% to the fan power requirements. The increased power cost in one years operation could exceed the purchase value of the silencer.

Although hearing conservation is the main design criteria for underground auxiliary fans, a design to minimise speech and signal interference may be required in workshops and at shaft stations. A mine will have between 50 and 100 auxiliary fan installations depending on its size. Investigations are in progress to design lighter silencers which are easier to maintain.

Rock drills

If pneumatic rock drills are used, a well designed filter or muffler will reduce the sound power of the exhaust by at least 95% (5 to 10 dB). This will normally be insufficient even when considering hearing conservation and consequently mufflers capable of removing in excess of 99% of the exhaust noise will be required. Unless the compressed air is reasonably free of moisture there will be icing in the muffler. Many mines will therefore need to improve the cooling arrangements at the surface compressors. The increase in back pressure caused by the muffler can reduce the drill penetration rate but this can be overcome by increasing the compressed air consumption, the small drop in overall efficiency normally being acceptable.

NOISE CONTROL IN UNDERGROUND MINING

For the noise produced from bending waves in the long drill steels, control measures are mainly based on reducing the magnitude of these vibrations. This includes ensuring that the thrust applied to the drill is optimum, using longer drill steel shanks and closer tolerances in the chuck and, maintaining as far as is practical, parallel impact surfaces. Plastic or rubber coatings bonded to the drill steel are fairly effective but substantially reduce the penetration rate. An alternative method is to enclose the drill steel with a telescopic enclosure which is not in contact with the drill steel. This later method can reduce this noise source by approximately 90% but is very cumbersome and has a very poor operator acceptance.

A similar problem exists when reducing noise from the drill body. The reduction in impact noise would impair the drill performance and a suitable enclosure inceases size and mass with poor operator acceptance particularly when hand held as opposed to cradle mounted.

Diesel powered equipment

Reducing engine noise by means of enclosures is complicated by the need for engine cooling. In most equipment used underground approximately one third of the heat produced is removed by the exhaust gases, one third by the engine cooling system and the balance by radiation and convection to the surrounding air and rock surfaces. Some progress has been made on reducing the noise level at the operator of the equipment by up to 7 dB by using acoustically designed cabs.

HEARING PROTECTION

From the foregoing sections it is clear that underground mine environments currently result in noise exposure levels between 100 and 120 dBA and exposure times of several hours per shift. Designing effective noise control systems for underground mining operations is a time consuming and expensive business usually without immediate or obvious solutions.

Ear protectors are therefore an important interim measure in any hearing conservation program. Environmental conditions within the workplace are often severe i.e. hot, wet and dirty and not condusive to the wearing of ear muffs. In these situations ear plugs are favoured despite potential problems with incorrect insertion.

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