MINING INDUSTRY
OCCUPATIONAL
SAFETY & HEALTH

Mining Industry Occupational Safety and Health

Industry – Wide Buy and Maintain Quiet Initiative

Equipment Noise Research Consolidation Report

Compiled by Mr. L.A. Meyer
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Abbreviations

CSIR	Council for Scientific and Industrial Research
DMR	Department Mineral Resources
SIMRAC	Safety in Mines Research Advisory Committee
MHSC	Mine Health and Safety Council
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational Exposure Limit
NIHL	Noise induced hearing loss
TWA	Time Weighted Average
HPD	Hearing Protection Device
NR	Noise Reduction

Industry – wide Buy and Maintain Quiet Initiative

Introduction

The Industry Wide Buy and Maintain Quiet Initiative (IBMQI) is a standing decision from the mining companies to procure new equipment (or machinery) and maintain existing ones in such a way that they comply with noise emission requirements. The Initiative is a noise source elimination of managing the noise hazard at the machine design phase. The collective demand from the industry will motivate manufacturers and suppliers to focus more on noise reduction as part of their product development. The IBMQI initiative acknowledges that individual mining companies have established Buy Quiet Policies and extended these to their procurement processes and Noise Induced Hearing Loss Campaigns albeit with limited success. The IBMQI emphasizes the partnering with and collective motivation of equipment manufacturers and suppliers to invest specifically in the development of quieter equipment. The industry largely worked in isolation in a bid to install effective means of reducing hearing loss, though there were some inroads with respect to Hearing Protection Devices (HPD's) and prevention of noise induced hearing loss training material, these too have become outdated. In the last twenty years the mining industry and government funded a number of research studies through tertiary and other institutions, the recommendations of which were only partially implemented and have become outdated.

In the last decade, individual mining companies have established Buy Quiet Policies have met with limited success. A number of recommendations to build additional prototypes based on the research outcome, for testing in the physical underground conditions did not realize.
In order for industry to be sustainable in future and with the effects of globalization, the mining industry is going to become even more mechanized. Therefore, it is imperative to manage noise at the design stage of the machinery/equipment. With equipment life of 5 to 10 years or longer, industry must become proactive and play a collective facilitative role towards 'real innovation' that can significantly lower noise at source. Industry-wide cooperation with suppliers will create a win-win result for both parties as suppliers that already meet the legal requirements will have the potential to offset their development cost against a potential increase in market share. Industry has spent a substantial amount of money over the last decade in compensation for the high noise emitted by machinery. Profitability and sustainability challenges make this scenario going forward very expensive. It is substantially cheaper for mining companies to embark on an Industry Wide Buy Quiet and Maintain Quiet Initiative as opposed to individual company reactive engineering developments and PPE.

The mining industry's zero harm vision and the commitment that mining companies have made towards elimination of noise hazards in mining is compelling. Despite the good work and progress made, mining industry did not manage to achieve the 2008 milestone that was set in 2003 and have regrettably also not done so by 2013. To effectively manage the noise hazard, there is a general consensus that the industry will have to focus most of their energies on source elimination initiatives and this sets the pretext and importance of collective leadership involvement in addressing the noise hazard.

A large amount of research has been conducted on “Noise Controls” and “Noise Reduction” on mining equipment. The research commenced in 2003 when the milestone was set for the mining industry to achieve specific targets. At the time the various mining houses implemented various strategies through the Original Equipment Manufacturers (OEM), and employed consulting and or research institutions to carry out work on “Equipment Types” that were identified as “High Pressure Level” contributors. This research however was largely done without collaboration of other mining houses and possible successes were therefore not shared.

Project Overview

The Noise Research Consolidation team has been tasked to establish “What” previous research was conducted by the mining industry and others with respect to noise reduction, and more specifically toward equipment and machinery changes that assisted in reducing noise levels. Establish which of the remaining OEM’s participated in the noise reduction studies that were conducted by the various mining houses and approach the same to establish the successes and or failures that emanated from such studies.

Establish the successes that lead to the conversion of equipment and establish the current performance and noise pressure levels against the current Standards for Noise Pressure Level testing. The project will also make contact with various tertiary institutions and consulting houses to determine the extent of their involvement in noise reduction research and the papers published in line with the research outcomes.

Objective

The objective of the Noise Research Consolidation team will be to document the outcomes of each of the available independent research papers, thus enabling a Gap Analysis to be compiled.

Strategic Alignment

The Noise Research Consolidation team commenced with discussions with the various tertiary institutions, research organizations and consulting houses to establish and obtain copies of previous research work conducted in the field of noise reduction.

The team endeavored to contact role players that were involved in equipment noise reduction research and found that very few of the role players involved were still at the institutions that conducted the research work, and those that were still at the institutions could only provide copies of the research work that they had on file. A number of the institutions had no contact details of the persons that had left the institution.

Major Deliverables

The project will include but not be limited to;

- The compilation of a register of all persons and contact numbers at the various institutions with whom discussions were held with respect to the project.
- A register of the research paper authors.
- The compilation of a register of all Noise Research Projects undertaken by the various institutions.
- A summary of the outcomes of the projects undertaken by the various institutions.
- A Gap Analysis prepared from the positive outcomes of research already conducted, against "Where we currently" in the mining industry.
- A Gap Analysis to establish the requirements in order to transform the mining industry to "Where we want to be".

Institutions and subject matter experts

The following institutions and subject matter experts will be used as a starting point and used to build a comprehensive research register.

- University of the Witwatersrand
- University of Johannesburg
- North-West University
- University of Pretoria
- University of the Free State
- Chamber of Mines
- SIMRAC
- CSIR
- Mining Houses
- Mine experts (Bill Erasmus)
- Turgis (Royal Haskoning DHV)

List of tertiary institutions.

Tertiary Institution	Contact Persons	Response
University of the Witwatersrand	Mr. Terrance Frangakis, Prof Declan Vogt	No research in 'Noise control in Mining. Referred me to CSIR
University of Johannesburg	Elma Taylor and Fanoro Mokesioluwa	No Research in 'Noise control in Mining'
University of the Free State	No Engineering dept.	Don't have an Engineering Research Department
North West University	Harry Wichers and Sanette Loots	No Research in 'Noise control in Mining'
University of Pretoria	Prof. Stephan Heyns, Prof Nico Theron and Mr. Rudi Kroch	Number of research projects in collaboration with CSIR

List of other institutions.

CSIR	A Edwards, P. Schutte	Copies of SIMRAC projects and other research papers
Business enterprises U.P.	Prof. P.S. Heyns, Rudi Kroch	Involvement in MHSC research.
Sasol Projects	I. Labuschagne	Dura and jet fan testing.
Axial Flow	C. Zerbst	Dura fan
Trident	M. Calver	Loader silencing development
Salzgitter	D. McNeil	Progression of the Salzgitter Rail-bound throw loader
JSN Engineering	L. J. Le Roux	Development of the "Remote controlled winch"
Royal Haskoning	K. Reading	No response
SIMRAC	C. Gomes	No response

List of research papers

A complete register of all research papers obtained is attached. The list entails the title of the research paper, the institution responsible for the research, the authors of the research paper and the year in which the research was conducted.
The register is sequenced according to the year it was conducted and covers research papers from 1997 to 2015, with the bulk of the research having been conducted before 2010.

Research documents divided into practices and equipment

a) Practices related papers

	Title	Subject
1	NIHL Prevention program	Training and awareness
2	Rock drills used in South African mines	Compare noise and vibration levels.
3	A technique for estimating the sound power level radiated by pneumatic rock drills and the evaluation of a CSIR prototype rock drill with engineering noise controls.	Measurement method, dimensions, measurement equipment and standards used to evaluate the sound power level.
4	The noise induced hearing loss milestones past and future	Analysis of noise induced claims
5	Meeting the milestones: Are South African small to medium mines up to the task.	Audit against DMR guidelines for hearing conservation programs
6	Profiles of noise exposure levels in South African mines	Two year study focused on exposure levels in the South African mining industry.
7	Noise induced hearing loss prevention in the South African mining industry (Presentation based on the above paper)	Measurement of personal noise exposure levels
8	Preventing adverse effects of noise and vibration in the South African mining industry	Effects of noise and vibration by consolidating existing knowledge. Booklet – A particle guide to noise and vibration control.
10	The attenuation of rock drill vibration	An attempt to quantify the out-comes of human vibration by mathematical modeling.
11	Noise controls for mining equipment	Evaluation the standard for above and underground measurements and demonstrate the projection of underground noise.
12	Occupational Hygiene report on workplace noise (Sasol – Noise reduction)	Has bearing on the testing of the reduced speed ventilation fan – see also Dura Fan under equipment/ engineering related papers.

b) Equipment/ engineering related papers

	Title	Subject
13	Design and development of a quiet self-thrusting blast hole drilling system. (GAP 642)	Design of a rock drill enclosure to reduce noise levels
14	Design and development of a low noise rock drill	A re-visit of the GAP 642 work to develop noise reducing enclosures for rock drills.
15	An examination of methods whereby noise levels in current and new mining equipment may be reduced.	Noise control at source and noise reduction by treatment remote from the source.
16	Noise control in underground metal mining	A booklet that details the noise problems, controls, and analysis and sound levels, with some test work carried out on TMM.
17	Analysis of a mechanism suspension to reduce noise from horizontal vibrating screens.	Tuned mechanism suspension could reduce the weighted sound power level
18	Noise controls for mining equipment	Absorptive material and enclosures
19	Wright 356 load haul dumper	Study and recommendations for acoustic enclosure design.
20	Progression of the Salzgitter Rail-bound throw loader for safer, efficient and reliable mining.	Progress in noise reduction from pneumatic to hydraulic, electro-hydraulic and electric loaders.
21	Noise reduction progress in rail bound loaders (Includes Atlas Copco and Lennings)	Progress made through R&D on the Eimco rocker shovel noise reduction
22	Dura fan	Re-design to achieve reduced noise emissions.
23	Electro-mechanical remote operated winch – JSN	Re-design of scrapper winch to allow remote operation and the effect on noise reduction.
24	Noise impact study and the requirements for mitigation of the Bank No. 5 surface ventilation fan.	Sound power level study on specific equipment type, outcome and recommendation.
25	Engineering noise control	Source and control at source

Discussion on Practices Related research documents

Exposure rather than noise levels emitted by Machines *

It appears that the single most important aspect that was used to drive research from 2000 to 2010 was based on "work types" where the levels of exposure to which the workers were exposed were measured. The driver being the South African mining regulations which specifies the dB (A) to which a person may be exposed over an 8-hour period.

(* See graphical representation on pages 11 and 12)

Discussion on graphical representation

The graphical representation is an extract from a presentation compiled by A. Edwards of CSIR, the graphical representation is also found in other research papers (1-3). From the graphical representation it is apparent that the levels of exposure to which the workers were exposed were measured and not the sound power levels emitted by the equipment.
Knowing the work place or interface that the following workers were employed in would have assisted in identifying the equipment types that had an impact on their exposure levels, for example;

- Multi task workers,
- Other team leader,
- Engineering assistant,
- Mechanical assistant,
- Equipment helper.

From the research conducted and information provided on "work type" exposure levels the employers embarked on various "Hearing Conservation Programs" (HCP) to reduce the number of NIHL claims. This included "hearing protection devices" (HPD).

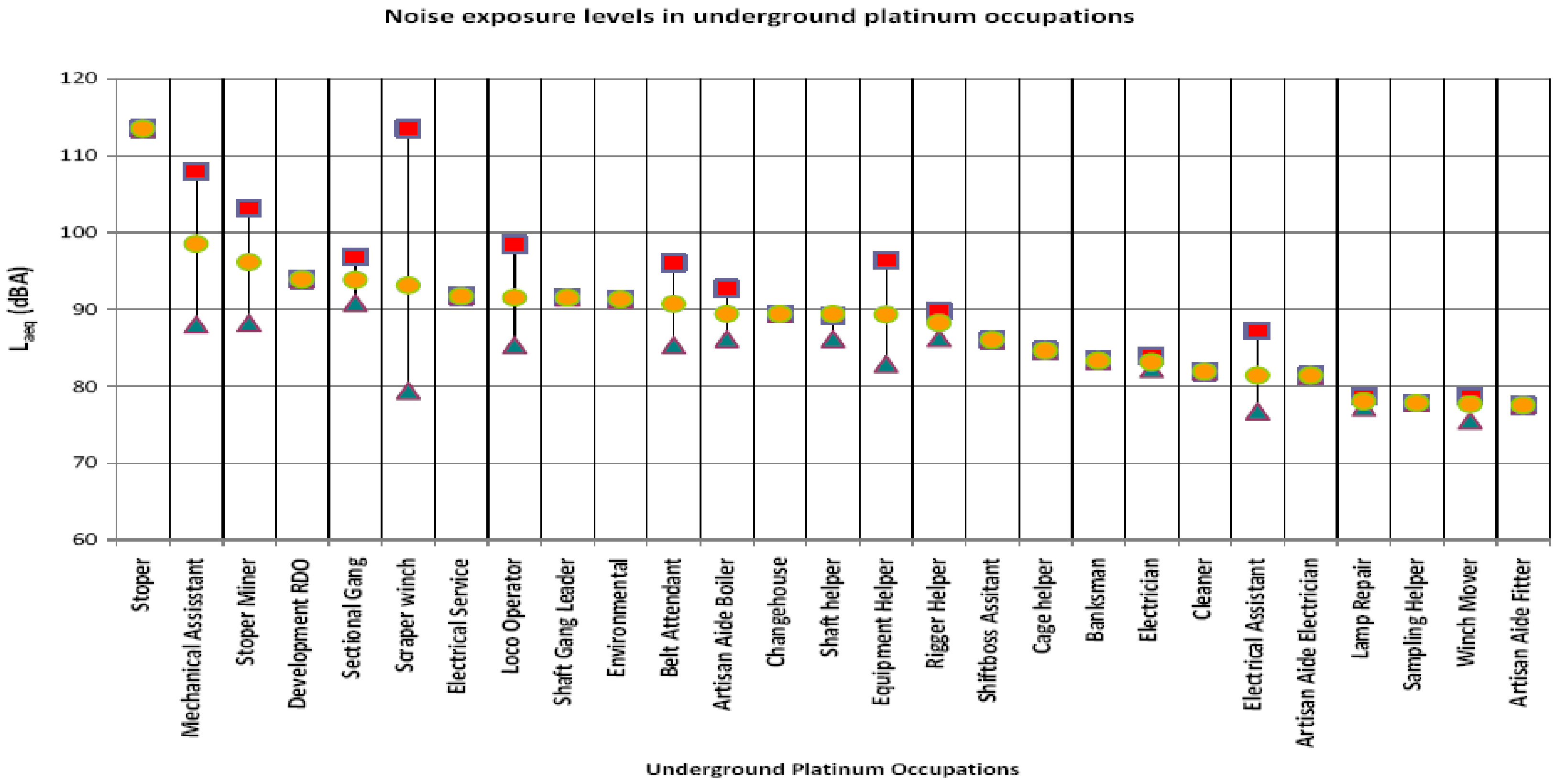
The problem with following this route was that employees did not understand the importance of using the HPD's as part of their PPE.

Despite the implementation and ongoing efforts to improve the effectiveness of mine hearing conservation programs, noise induced hearing loss (NIHL) has cost the mining industry hundreds of millions in compensation claims.

Even with efforts to reduce noise emissions through re-engineering and re-design the requirement for HPD's will remain an integral part of the mines hearing conservation program.

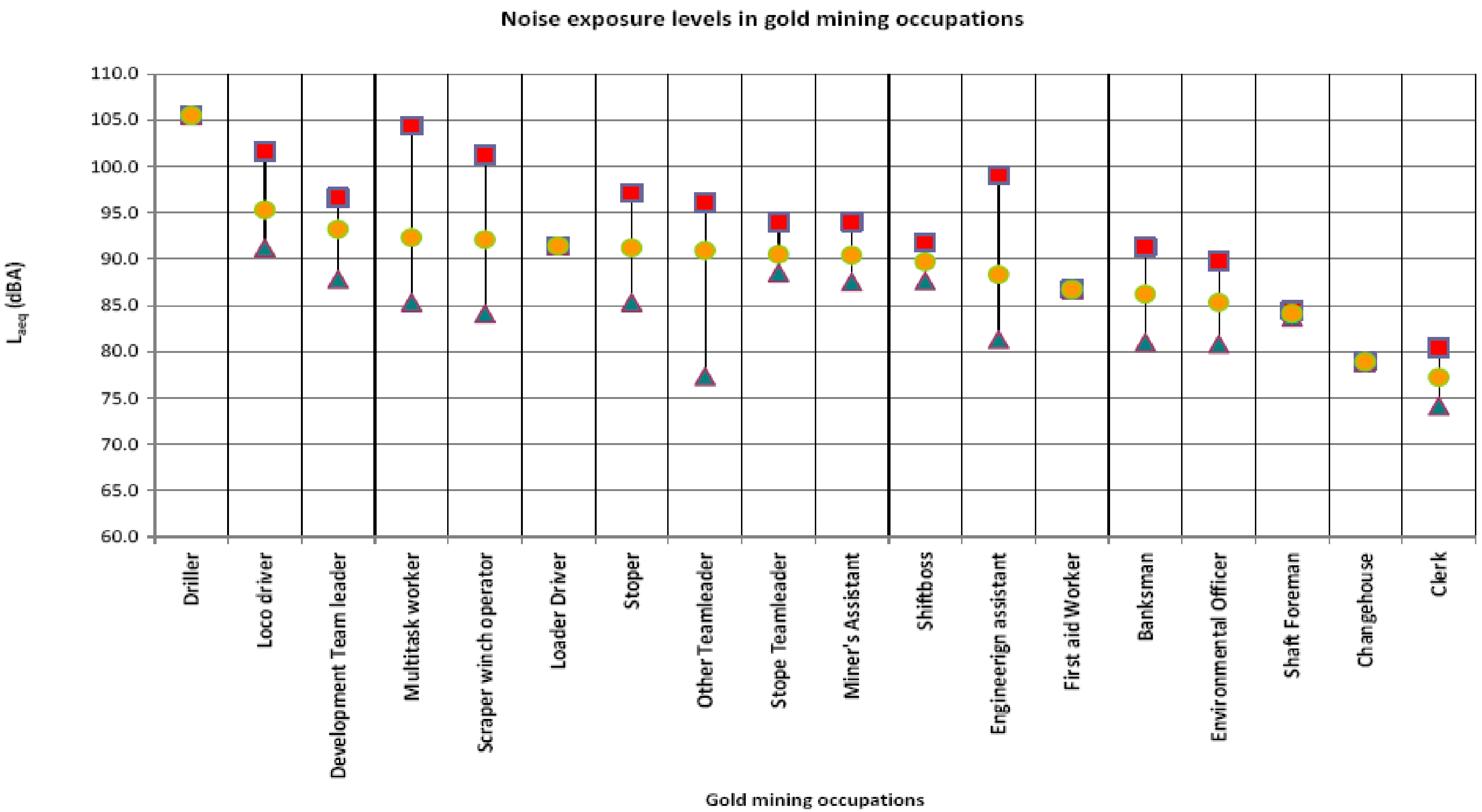
Graphical representation of "Occupations" per work type

Platinum Mines



(Extract from The journal of The South African Institute of Mining and Metallurgy – A.L. Edwards, J.J. Dekker, R.M. Franz, T. van Dyk and A. Banyini)(1)

Gold Mines



(Extract from The journal of The South African Institute of Mining and Metallurgy – A.L. Edwards, J.J. Dekker, R.M. Franz, T. van Dyk and A. Banyini)(1)

Discussion on equipment/ engineering related papers by equipment type

Rock drills

There was research work completed on a prototype acoustically shielded, self-propelled rock drill, the acoustically shielded self-propelled rock drill was discussed under a number of differently titled papers with minimal changes to the papers. The only papers that differed considerably were that of the actual development and test and a research paper that was dedicated to the full testing of each of the differently powered rock drills: namely pneumatic, hydraulic and electric with the electric drill being the quietest but the slowest rock penetration, with the hydraulic drill having a moderate noise level but the fastest rock penetration.

With the design and development of the quiet self-thrusting blast hole drilling system progress had been made on previous work conducted by SIMRAC. The experimental development model showed promise in reducing sound power levels but had a number of drawbacks which precluded it from being implemented in production (4). Further research was carried out on drill steel and simple treatments which were either well proven or readily available or which had been shown to be reasonably effective but not widely employed in the field. These retrofits included a wrap-around muffler achieving a 7 – 10 dB (A) reduction, a constrained layer damped drill steel (collar) with wrap-around muffler achieving 10 – 12 dB (A) reduction and a shrouded drill steel with wrap-around muffler achieving 10 – 15 dB (A) reduction (5).

A workable retrofit was developed under contract for the acoustic enclosure for boom mounted rock drills. The top half enclosure hinged open from the bottom half, allowing easy access to the drill. From discussions with rock drill suppliers/ repairers it appears that not much has been done over the past 10 years in further development of the pneumatic rock drill to achieve reduced sound power levels. It has also been noted that development has increased on the hydraulic powered rock drills, with HPE developing moveable power packs are capable of powering a number of rock drills simultaneously. Similarly, it was noted that Atlas Copco have now entered the market with a smaller hydraulic power pack, capable of being transported by two people.

Electric Motors

Very little work has been done on the reduction of sound power levels on electric motors as most of the work must be incorporated at the design stage of the electric motor. In one of the engineering controls for noise reduction papers there was some development that achieved a small sound power reduction through the design change of the motors cooling fan blades (6).

Ventilation Fans

In the paper titled, examination of methods whereby noise levels in current and new mining equipment may be reduced, the following areas were covered: fan absorptive silencers, fan reactive silencers, fan active noise control and fan re-design/ modifications. The fan silencing is based on the current absorptive silencers used in the industry today, the fan active noise control is based on the concept of active noise control cancelling the existing noise by the creation of an “anti-noise” of the same amplitude and frequency as the offending noise but exactly 180° out of phase.

Active noise control is now a well proven solution to many low frequency noise problems associated with fans and compressors in general industrial applications. Fan re-design constitutes the requirement to reduce the blade tip clearance, which in itself would not lower the sound power level but would increase the efficiency thus allowing the speed to be decreased which in turn would lower the sound power level of the fan. One fan manufacturer, Axial Flow fans carried out test work with design changes that allowed the fan speed to be reduced from 2900 rpm to 1450 rpm and maintained efficiencies with lower maintenance cost, lower running cost and lower sound power levels. The slower radial speed of the impeller produces less vibration when newly installed and less vibration with accumulation of dust thus producing lower vibration frequencies resulting in reduced sound power levels throughout its operation (7, 8). From test work it was found that the sound power on a 7.5 kW fan was reduced from 89 dB (A) to 75.2 dB (A) at 1 meter from the installation(7).

Trackless Mining Machines

Most of the research, test work and papers received were disappointing; the machines upon which test work and silencing was performed covered the old generation machines where the drivers cab, engine and transmission were not of the enclosed type. The test work performed on load haul machines used in pit mining was also of the open cab type machines. The recommendations on some of the noise generating ancillaries are still valid, such as exhaust silencers/ mufflers. Recommendations for engine compartments and cabs eluded on enclosures lined with absorptive materials. No research work, presentations or reports could be located to establish the noise levels of the new era air-conditioned closed cab load haul dumpers.

Vibrating Screens

Extensive work was done in this area by calculating the “degree of freedom” (DOF) and secondly by conducting a “Finite Element” model, both systems were used to establish the position and weight of the counterforce that would be installed. The goal of adding the mechanism suspension is to separate the primary source of mechanical energy from the noise radiating structure, but without degrading the performance of the screen. The system successfully attenuates noise and vibration above 100Hz, but because their pitch modes would be close to the screen’s operating speed, these could cause undesirable behaviour during start-up, shutdown and steady operation.

Pneumatic Rocker Arm Shovel Loaders

This is an area where a lot of development has taken place over the last ten years, both the major suppliers: Trident South Africa and Salzgitter Mzansi have developed electro hydraulic loaders that have shown a respective reduction in the sound power levels(9, 10). Salzgitter Mzansi has progressed with further designs and is now supplying the electro hydraulic rocker arm shovel as a remote controlled machine which removes the operator from the direct line of the remaining sound power levels(11), with a complete electric remote control loader in development.

Scraper Winches

There has been little to no design modifications to reduce the sound power levels of scraper winches where the operator is required to be positioned in direct proximity of the sound power generated by the motor, gearbox and winch drums. AngloGold Ashanti (AGA) has partnered with JSN Engineering who are in the process of developing, firstly a remote controlled winch that will not only remove the operator from the direct vicinity in which the sound power is generated (12), but will also remove the operator from the dusty area, secondly the development of a fully automated scraper winch system that will totally remove the operator from the vicinity at which the scraper winch is operating. The first prototype of remote controlled scraper winch has been developed and built and prototype testing witnessed by AGA representatives.

Silencing and acoustic damping

In a number of the research papers and more specifically where damping can be carried out the damping absorptive materials more commonly used in the industry, like fiberglass blankets and thick quilted fiberglass absorptive materials. Testing in the exact same equipment/ machines in the exact same areas with 6mm conveyor belting proved to reduce the sound power levels generated by up to 5 times that of the absorptive damping materials on the market.

Concerns

No research work could be found for noise reduction on the following equipment used in the industry:

- Main compressors inclusive of speed increaser gearboxes and motors (RIV, RIK etc.)
- Main pumping inclusive of motors (Multistage pumps)

Current projects have recognized through Finite Element Analysis the component/ area responsible for sound power generation through vibration can be identified, though vibration is a major contributor to noise emissions the current studies lean toward the impact that vibration has on the person.

It is advised that further investigation be undertaken with some of the vibration specialists in the industry to correlate vibration and sound power levels against the reduction in vibration through balancing and or component replacement and measurement of noise reduction through the corrective action of vibration reduction.

The research documentation that addresses equipment re-design and/ or acoustic damping should be re-visited and the areas in the mining industry where this has been implemented perused in order to share the benefits throughout the mining industry.

It must be noted that in certain instances that certain sections/ paragraphs have been directly inserted in the summary of the papers and reports, this to ensure that the correct understanding of the work done is carried across to the reader.

Gap Matrix

No	Title	Institution	Milestones Measurement	Addresses OEL	Awareness HPD	Vibration & Damping	Equipment Engineering Noise Reduction	Comments
1	A technique for estimating the sound power level radiated by pneumatic rock drills and the evaluation of a CSIR prototype rock drill with engineering noise controls.	NIOSH (Pittsburgh USA) CSIR (RSA)						Covers method of testing sound power level of rock drills
2	An examination of methods whereby noise levels in current & new mining equipment may be reduced.	SIMRAC GEN 420						Proposes a number of methods of damping sound on various equipment
3	The attenuation of rock drill vibration (GAP 634)	University of Pretoria						Include in future rock drill silencing work groups.
4	Design and development of a quiet self-thrusting blast hole drilling system (GAP 642)	SIMRAC/ University of Pretoria						Include in future rock drill silencing work groups. Difficult to manage.
5	Design and development of a low noise rock drill	University of Pretoria						Include in future rock drill silencing work groups. Difficult to manage.
6	Design and development of a low noise rock drill	SAIMM/ SIMRAC/ University of Pretoria						Include in future rock drill silencing work groups. Difficult to manage.
7	Wright 356 Load haul dumper upgrade requirements for noise control	Anglo Coal						Specifies requirements for damping
8	Handbook on Mine Occupational Hygiene Measurements	MHSC/ University of Pretoria						
9	Bank No. 5 Shaft surface ventilation for noise impact study and requirements for mitigation.	Anglo Coal						Specifies sound power levels and requirements. No design change.
10	Rock drill used in South African mines: A comparative study of noise and vibration levels.							Include in future rock drill silencing work groups.
11	Progression of the Salzgitter Rail-bound throw loader for Safer, Efficient and Reliable Mining	D. McNeil (Salzgitter) SM/1711/DM/02						Equipment design change.
12	NIHL Prevention program - Track c Training, awareness & HPD selection	CSIR/ MHSC SIM 050501	GEN 011					Learning material enhancement

No.	**Title**	**Institution**	Milestones Measurement	Addresses OEL	Awareness HPD	Vibration & Damping	Equipment Engineering Noise Reduction	Comments
13	Noise control in underground metal mining	American paper						Use of absorptive materials for noise damping
14	Electro-Mechanical Remote Operated Winch	V. Le Roux (JSN Engineering)						Noise reduction through re-design of the winch
15	Noise induced hearing loss prevention in the South African Mining Industry.	CSIR (Presentation)						Occupational Exposure Limits in coal and gold mines.
16	Profiles of noise exposure levels in South African mining.	CSIR / SAIMM						Occupational Exposure Limits in coal and gold mines.
17	Meeting the milestones - Are South African small to medium scale mines up to the task.	CSIR / SAIMM						Compliance to DMR requirements by small mines
18	Analysis of a mechanism suspension to reduce noise from horizontal vibrating screens.	NIOSH (USA)						Use of finite element analysis and vibrational noise
19	The noise-induced hearing loss milestones: Past & future	CSIR						Measurement only
20	Noise controls for mining equipment	MHSC/ SIMRAC 120501 University of Pretoria						Covers scrubber fan test & silencing + test method spec
21	Preventing adverse effects of noise & vibration in the South African mining industry.							Whole body vibration.
22	Engineering noise control	University of Adelaide Australia						Disseminate report into NR areas that could benefit mines
23	Dura Fan	Axial Flow Fans						Equipment design change
24	Noise reduction progress in rail bound loaders	Mike Calver (Trident S.A.)						Equipment design change

	Addresses noise reduction through engineering design/ recommendation.
	Noise generated via vibration. Examine role of Condition Monitoring in reducing noise levels.
	Includes or addresses Hearing Protection Devices
	Looks at Occupational Exposure Limits
	Looks at NIHL milestones and/ or covers measurement/ audit.

Equipment Types that need to be addressed/ re-addressed

(This should be determined by taking the number of persons exposed per equipment type)

- Rock drills, hand and boom mounted
  - New generation hydraulic drills for performance, sound power and TCO.
- Ventilation fans
- Scraper winches
- Compressors
- Motors
- Trackless mobile machines
  - Need for understanding the volumes of old and new generation machines
- Conveyor loading and transfer points

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SIMRAC
SAIMM
MHSC
NOISH (USA)
University of Adelaide Australia
Anglo Coal
Trident South Africa
Salzgitter Mzansi
JSN Engineering
Axial Flow Fans
Ben Van Zyl

NIHL Prevention Program – Track C Training & Awareness & HPD Selection (RM Franz & AC Edward) SIM 050501 June 2009(13).

Addresses educational, motivational & training materials produced by GEN 011 for NIHL prevention in the form of video programs, booklets and guidelines for trainers. This project was aimed at the evaluation of the materials and make recommendations for the updating of the materials. The results indicated that during the ten (10) years since the development of the GEN 011 materials, only 52 training packages had been purchased and only five (5) mines were still using the materials purchased, six (6) had used them previously but no longer used them and eight (8) reported never having used them. The most popular component product of GEN 011 were the booklets, with English being the most popular choice of language medium(13). Most mines were identified, were focus groups and individual interviews were held with Mine Employees from Coal, Gold and Platinum Mines.

Criteria used for evaluating the educational, awareness and motivational materials were:

→ *Accessibility*:
Of the materials in terms of different mother-tongue language, different cultural practices and varying levels of sophistication and literacy.

→ *Motivational Value*:
Of the material for mineworkers to protect themselves from NIHL by explaining the risks and making the consequences of noise exposure clear.

→ *Relevance:*
Of the material to individual needs at different levels of authority and in various workplaces.

→ *Enabling Value:*
Of the material to inform and instruct clearly on the correct and effective use of hearing protection devices (HPD's) and HCD practice.

→ *Technical Quality:*
Of the materials with regard to image quantity, sound quality and availability of material.

Recommendations made to the MHSC:

→ *Relating to the video material:*

1. Video material should be distributed in DVD format only.
2. The Coal, Gold and Platinum versions should be consolidated into a single program.
3. The sound track (English and Zulu) should be re-dubbed to improve the sound quality.
4. Improve access by different language groups and for use in different acoustical environments should be provided.
5. Scenes and footage with female mineworkers should be included to improve relevance.
6. Old music to be replaced with contemporary music.
7. An audio demonstration of hearing loss and its impacts on speech intelligibility should be included.

Recommendations for updating the HPD booklet were as follows:

1. Panels with female mineworkers should be included.
2. Some of the pictures with HPD types should be revised to ensure that they are representative of what is available and common in use.

<u>Rock Drills used in South African Mines: A comparative study of noise and vibration levels (J.I Phillips, P.S Heyns and G. Nelson) (5)</u>

Objectives:

To compare the noise and vibration levels associates with three hand held rock-drills (pneumatic, hydraulic and electric) currently used in South African Mines, and a proto type acoustically shielded self-propelled rock-drill.

Methods:

Equivalent A-weighted sound pressure levels were recorded on a geometrical grid, using Rion NL-11 and NL-14 sound level meters. Vibration measurements were conducted on the pneumatic, hydraulic and electric drills in accordance with the ISO 5349-1 (2001) international standards on human exposure to hand transmitted vibration, using a Brel & Kjaer UA 0894 hand adopter. PCB Piezo accelerometers were used to measure vibration in three orthogonal directions. No vibration measurements were conducted on the self-propelled drill(5).

Results:

All four (4) drills emitted noise exceeding 85 dB (A). The pneumatic drill reached levels of up to 114 dB (A), while the shielded self-propelled drill almost complied with the 85 dB (A) 8h exposure limit.
Vibration levels of up to 31 ms^{-1} were recorded. These levels greatly exceed recommended and legislated levels (5).

Table 1. – Drill penetration rates (for the 6 configurations)

Configuration	Penetration rate (mm min^{-1})
Self-propelled drill with standard drill steel	300–400
Self-propelled drill with cladded drill steel	300
Pneumatic drill: standard configuration	350
Pneumatic drill: muffled configuration	395
Hydraulic drill	600
Electric drill	130

Table 2. – Sound pressure levels at the 3 grid positions

Configuration	Behind operator [dB(A)]	Right of the operator [dB(A)]	Right further back [dB(A)]
Self-propelled drill with standard drill steel	88.7	84.9	82.9
Self-propelled drill with cladded drill steel	84.1	86.1	84.1
Pneumatic drill: standard configuration	104.4	107.9	104.2
Pneumatic drill: muffled configuration	100.5	103.8	98.1
Hydraulic drill	98.9	103.4	98.1
Electric drill	92.4	94.7	94.6

Table 2 indicates the actual measurements at three (3) positions; about half a meter behind the operator, close to the operators right ear and 45° at 3 meters to the right and rear of the operator(5).

Summary

While the hydraulic drill had the highest penetration rate (600 mm/min), it produced medium to high sound pressure levels [103.4 dB(A)] and the highest vibration levels (31.0 ms^{-2}). The electric drill caused the lowest vibration levels (9.2 ms^{-2}) and medium sound pressure levels [94.7 dB(A)] but the penetration rates were low (130 mm/min). The pneumatic drill had medium penetration rates (350 mm/min) and medium noise [105 dB(A)] with high vibration levels (21.9 ms^{-2}). The self propelled drill was the quietest drill with the two (2) configurations at [84.9 dB(A)] and [86.1 dB(A)] respectively, with medium penetration rates of (300 – 400 mm/min)(5).

It is always better to effect engineering solutions to reduce a hazard at source, rather than relying on PPE to protect workers. The self-propelled drill produced by far the lowest sound pressure levels. These levels were well within the reach of the 85 dB (A) limit even if the drill was to operate continuously for an 8-hour period. The standard conventional pneumatic drill generated the highest noise levels, as high as 114 dB (A) at some positions. The muffling reduced the sound pressure levels marginally, by 3 – 4 dB (A)

Table 3. – Vibration levels of three (3) rock drills (standard configuration)

Drill	a_{hwx} (m s^{-2})	a_{hwy} (m s^{-2})	a_{hwz} (m s^{-2})	a_{hv} (m s^{-2})
Pneumatic drill	10.9	6.0	18.0	21.9
Hydraulic drill	13.3	9.7	26.3	31.0
Electric drill	6.0	4.7	5.2	9.2

The vibration levels recorded for the three types of rock drills in standard configuration (excludes the self-propelled drill) are recorded in Table 3. Vibration from the hydraulic drill was particularly high at 31.0 ms^{-2}. The vibration from the pneumatic drill was lower at 21.9 ms^{-2} and as expected the muffling made no difference to the vibration measured. The lowest level of vibration was recorded for the electric drill at 9.2 ms^{-2}(5).

Table 4. – Summary of penetration, noise and vibration measurements for each rock drill configuration.

Configuration	Penetration rate (mm min^{-1})	Noise[a] [dB(A)]	Vibration[b] (m s^{-2})
Self-propelled drill with standard drill steel	300–400	84.9	Not measured
Self-propelled drill with cladded drill steel	300	86.1	Not measured
Pneumatic drill: standard configuration	350	107.9	21.9
Pneumatic drill: muffled configuration	395	103.8	21.9
Hydraulic drill	600	103.4	31.0
Electric drill	130	94.7	9.2

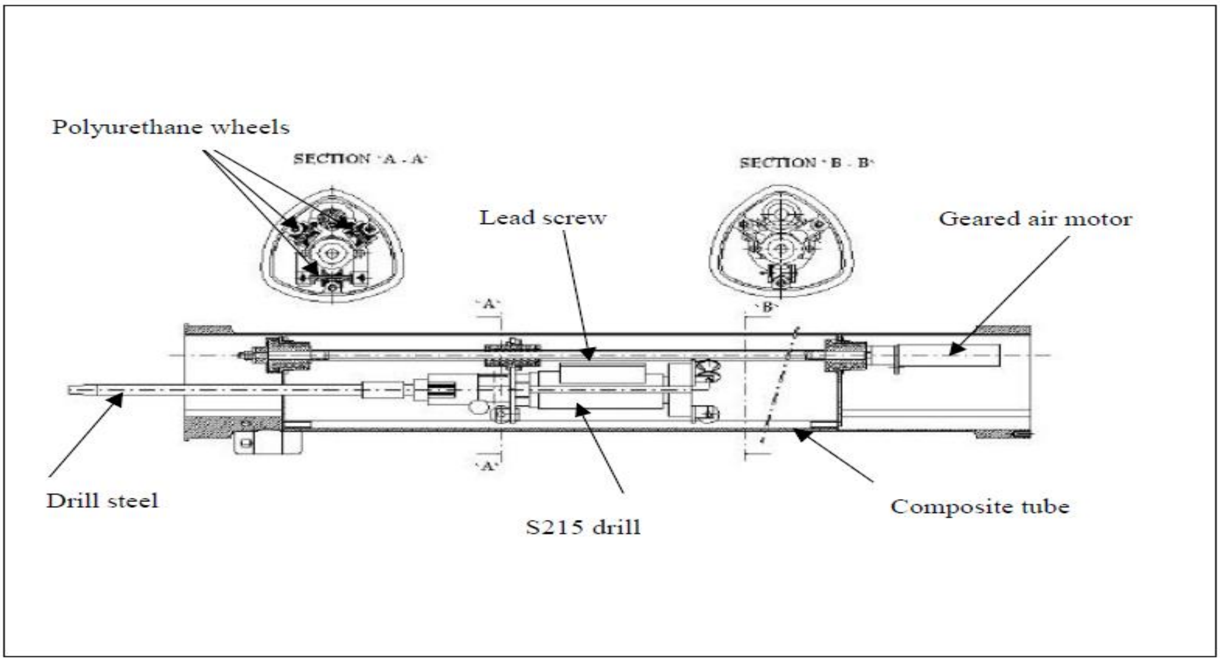
Discussion and Conclusion

The present noise exposure limit specified in South African Mining regulations is 85 dB(A) over an 8 hour working day, but this applies to the levels to which workers are exposed (with PPE, if necessary) rather than the levels emitted by the machines.

Bearing in mind that every 3 dB(A) increase in noise level requires a 50% reduction in exposure time, a 2-hour shift equates to maximum impacted levels of around 91 dB(A). It is therefore clear that typical noise levels on conventional equipment are still too high. This emphasis the need for further development on alternatives such as electrical and the self-propelled acoustically shielded drill.

Design and development of a quiet, self-thrusting blast hole drilling system (GAP 642, SIMRAC, University of Pretoria, August 2001 – R.W Otterman, N.D.L Burger, A.J von Wielligh, and P.R de Wet) (14)

Figure 1. – Experimental development model drill assembly



Introduction:

Some progress has been made during previous work by SIMRAC to develop a quiet drilling system, GEN 207 (Harper and Scanion, 1998). The experimental development model, GEN 311, showed promise in reducing sound power levels but has a number of drawbacks which precludes it from being implemented in production. It was decided by SIMRAC that a new approach to the development of a quiet rock-drill is needed (14).

Concept Design

Two concepts were generated that encapsulated the drill while the exhaust air and water is ducted away from the operation via a pipe. Dust caused by the drilling is also contained and ducted away, which reduces the health risk with related diseases. A possible addition is a waste unit where the oil and grease can be recovered to limit pollution (14).

Composite Material Tube

The drill is encapsulated in a composite material tube, which is pushed onto the rock face. The tube is sealed at the rock face by means of a flexible material. A thrusting mechanism, powered by a geared air motor, thrusts the drill forward. Exhaust air, rock chips, oil and grease are removed from the tube via an exhaust pipe a distance away where the air and water are dumped (14).

Composite Material Tube Concept

- Positive Factors:
  * Will be effective to stop high frequency airborne noise
  * Easy to increase sound isolation properties by adjusting the thickness and stiffness properties of the tube
  * Can make use of sandwiched structure to increase damping in the wall of the tube
  * Act as plankton to reduce noise from exhaust air
  * Relatively easy to manufacture
  * Can be made rigid with good strength and durability
  * Grease pollution in slope can be reduced
  * Fire resistant materials can be selected (14)

- Negative Factors:
  * Transmission of vibration via drill steel to the wall of the tube can reduce the isolation significantly
  * Sealing of the tube at the rock face will be difficult. Leakage will reduce noise isolation
  * Exterior surface can be a "speaker" at low and high frequencies
  * Air power required may increase slightly
  * Balky to transport
  * Maneuverability (14)

Figure 2. – Flexible bellows concept

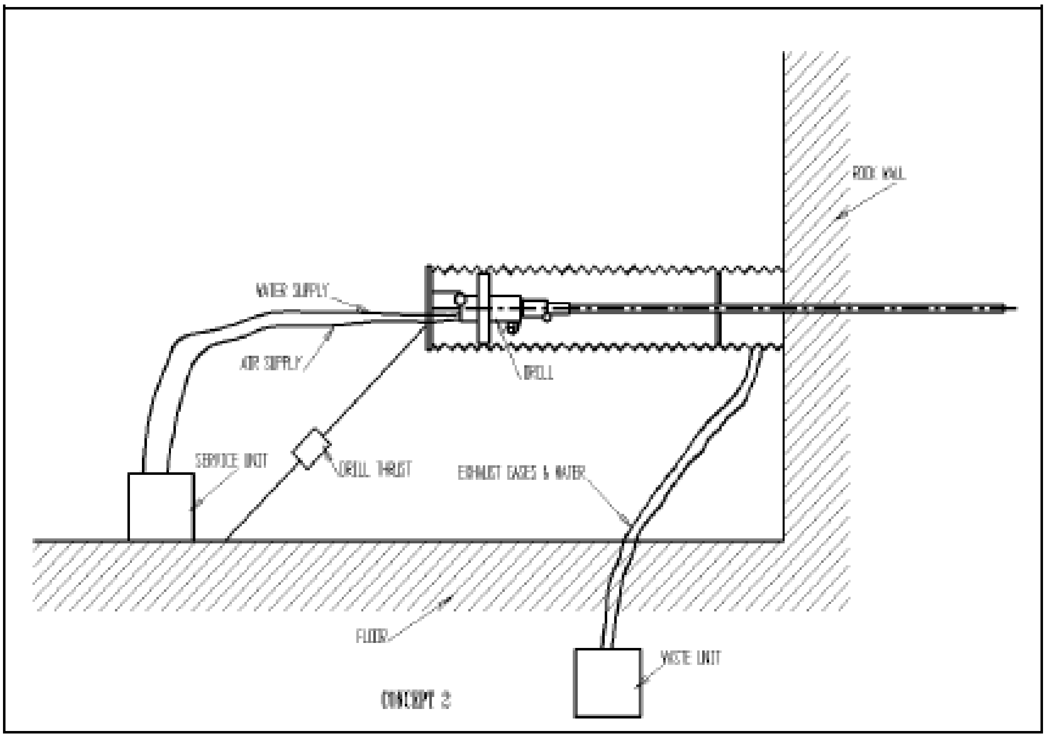
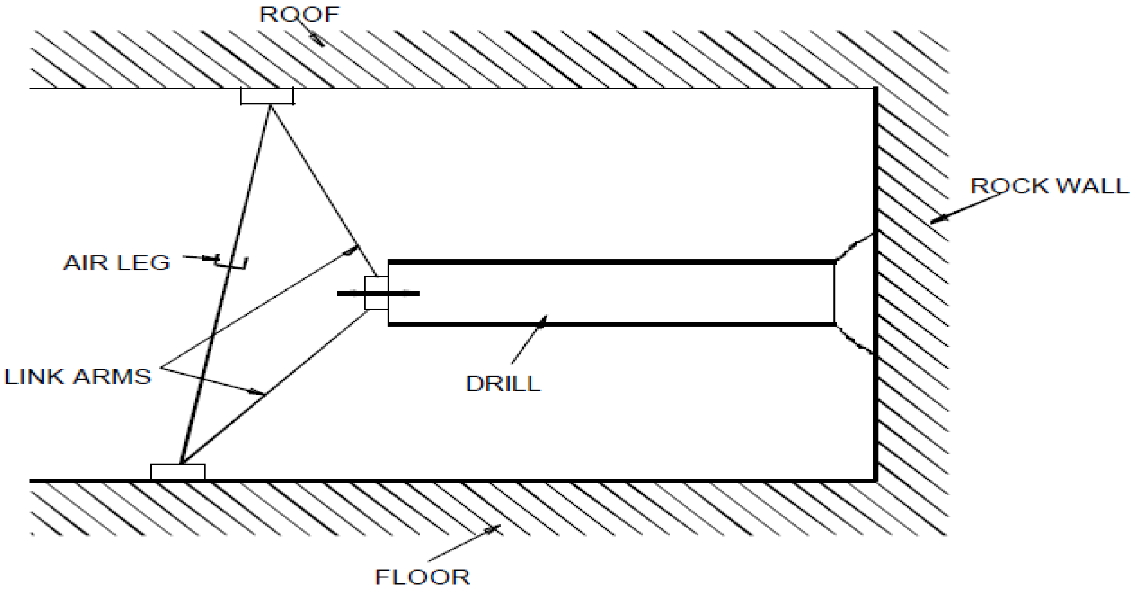


Figure 3. – Support of the rock drill air leg activated linkage system



Durability

Although no durability tests were performed, the drill was disassembled after the tests and all the components were inspected for any breakage and wear.

The identified components that were redesigned included:

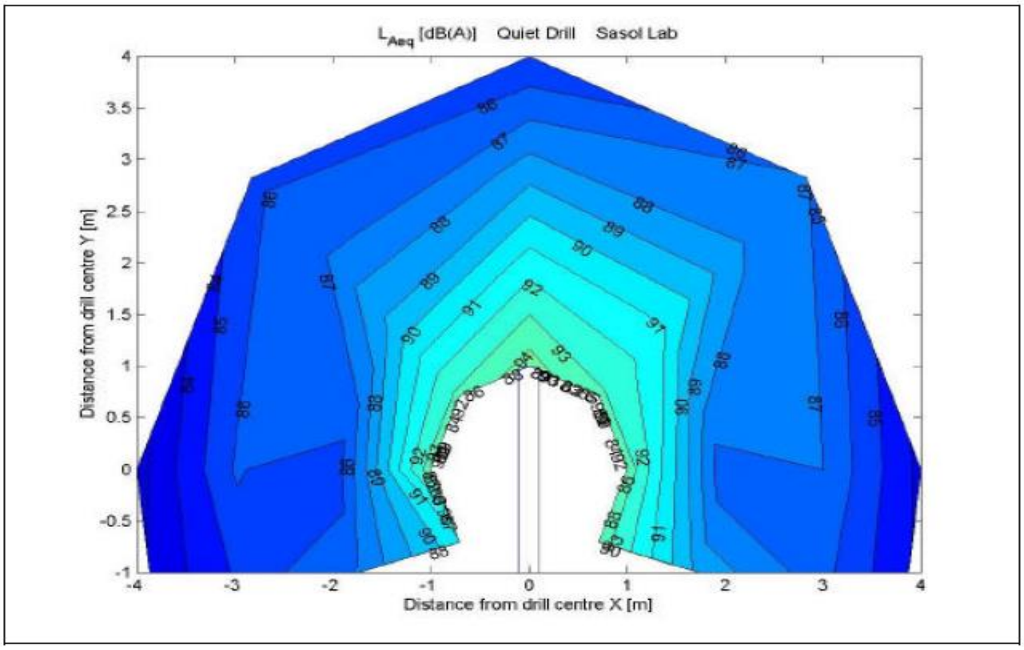
- → Design of hanger brackets connecting the rock drill to the lead screw. Changed to improve stability and durability. (Durability problem)
- → The bottom polyurethane wheel was replaced with a nylon wheel. (Durability problem)
- → The standard Boart Longyear lead screw was used (Durability problem)
- → Due to the Boart Longyear's lead screw differing to the geared air motor, the motor was changed to a 30 Nm air motor
- → The valve to control the flow of the water is incorporated into the back of the standard drill
- → A pneumatic (spiking cylinder) was mounted in the back plate for pushing the drill against the rock face
- → Air supply hose inside of tube increased to 19mm to reduce pressure drop
- → Valve block design changed to incorporate air inlet valve
- → Valve block material changed (Durability problem)
- → New design of seal against rock face
- → Inspection hole was added to tube
- → Tube shortened to accommodate shortens drill rod (1,2m)
- → Depth indicator added
- → Thickness of tube reduced to 3mm
- → Thickness of endplates increased to 10mm to accommodate thrust
- → Coupling between air motor and lead screw was changed to achieve better life (Durability problem)
- → Support at back of drill making use of a standard camlock
- → Support of drill at the rock face making use of an A-frame (14)

Test and Evaluation

Surface tests of the prototype quiet rock drill, drilling into a “Norite” block were done. The tests were done in an open area to reduce the effect of reflections from hard surfaces adding to the sound pressure level.

The noise levels were measured at predetermined points spaced on a 1m contours between 1m and 4m around the drill and the achieved results are shown in the figure below.

Figure 4. - Sound levels dB (A) around the prototype quiet rock drill (14)



Conclusion and Recommendation

A quiet, self-thrusting blast hole drilling system was developed and demonstrated. The system will have reduced hearing loss and increased productivity as operators can operate more than one system. A considerable reduction in sound levels was achieved with comparable drilling speeds to standard pneumatic drills. Although sound levels of below 90 dB (A) were not achieved directly adjacent to the quiet rock drill, the sound levels measured on surface are below 90 dB (A) at a distance of 1 to 2 meters away from the drill. As the operator will only be close to the drill for a very short period of time and for the majority of time will be further than 2 meters from the drill, this may not pose a problem (14). The tests of the quiet rock drill identified certain shortcomings including the weight and maneuverability, which will have to be further addressed during further development of the drill.

For further development of the drill the following is recommended.

- Do a design review to address shortcomings (reduce weight and reduce noise levels)?
- Change the drill or build new drills until the required performance is achieved.
- Do underground operational evaluations
- Do reliability tests(14).

Design and development of a low noise rock-drill (R.W Otterman, N.D.L Burger, A.J von Wielligh, P.R de Wet, J.L Steyn – South African Institute of Mining & Metallurgy, August 2004) (4)

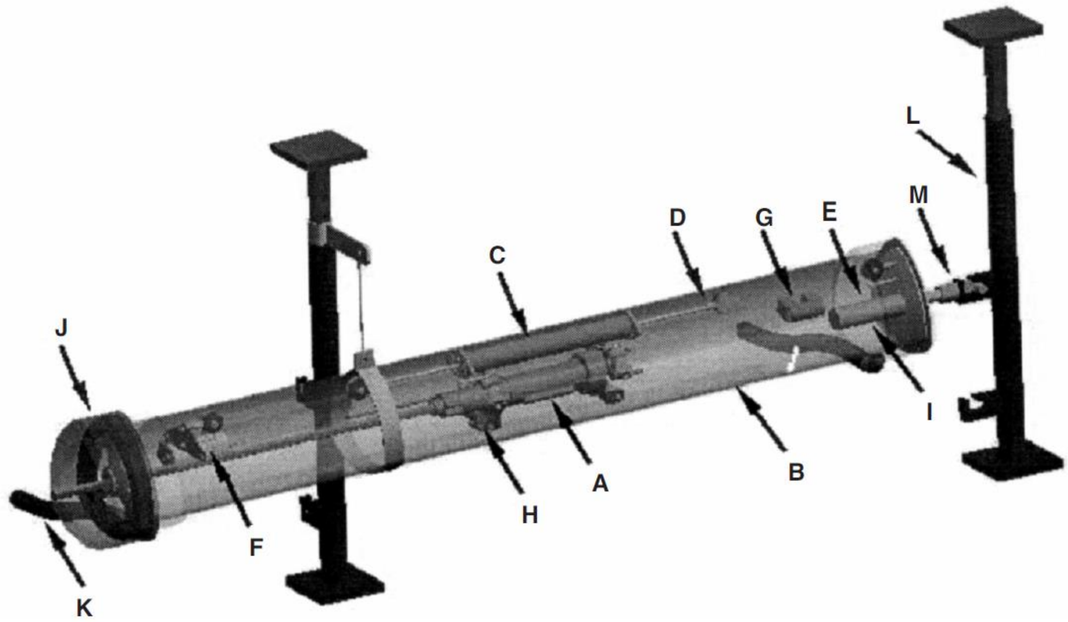
Introduction:

Some progress has been made during previous work by SIMRAC to develop a quiet drilling system, GEN 207 (Harper and Scanion, 1998). The experimental development model, GEN 311, showed promise in reducing sound power levels but has a number of drawbacks which precludes it from being implemented in production. It was decided by SIMRAC that a new approach to the development of a quiet rock-drill is needed.

Concept Design

Two concepts were generated that encapsulated the drill while the exhaust air and water is ducted away from the operation via a pipe. Dust caused by the drilling is also contained and ducted away, which reduces the health risk with related diseases. A possible addition is a waste unit where the oil and grease can be recovered to limit pollution.(4)

Figure 1 – Low noise rock drill assembly



The design uses a standard Seco S215 pneumatic rock drill (A) encapsulated in a fiberglass reinforced plastic tube (B) of triangular construction. The tube wall has a layered construction. The drill is propelled forward by means of a pneumatic cylinder (C) located inside the tube, which propels the drill via a Kevlar rope and pulley system (D). The air enters the drill from the rear and is controlled at the main control valve (E). The operation of the drill is controlled with two shuttle valves, one in the front (F) and one at the rear (G). The action of these valves is to automatically reverse the penetration run of the drill when the hole is completed and then to stop it at the zero position at the rear. The drill is supported in a wheeled carriage (H) that rolls on tubular ribs provided in the encapsulating tube for stiffness.

At the rear of the encapsulating tube a spiking cylinder (I) is mounted. The function of the cylinder is to thrust the drill assembly against the stope face. The force exerted by the cylinder is 3000N. The encapsulating tube is sealed against the rock face by means of a seal (J) which is compressed by the action of the spiking cylinder. The force is reacted by a camlock (L), an adjustable length roof support strut that is widely used in underground mining operations. The exhaust stream (air containing rock dust particles, water, oil and grease) is removed from the encapsulating tube via exhaust tubes (K) to the end of the stope (4).

Summary of design parameters for low noise rock drill.

Design Parameter	Value
Drilling speed – 40mm drill bit	>370 mm/min
Max. air consumption (Drill & ancillaries)	60 l/sec
Supplied air pressure: Maximum Minimum	 500kPa 300kPa
Maximum water consumption	11 l/min
Water pressure	>300 kPa
Maximum sound power level	90 dB(A)
Percussion rate	40 Hz
Thrust needed for drilling	1570 N
Drill steel length	1.2 to 1.8 m
Maximum mass of system	60 kg
Maximum diameter of system	240 mm
Color	Bright
Robust	Drop 1m onto 50mm diameter steel rod – drill must still be functional.

Discussion and conclusion

This SAIMM paper is based on the research work conducted in GAP 642 carried out by the University of Pretoria (14).

A technique for estimating the sound power level radiated by pneumatic rock drills and the evaluation of a CSIR prototype rock drill with engineering noise controls (P.G Kovakhik, F.T Duda & G.S Harper) NIOSH Pittsburgh/CSIR) (15)

Introduction

Several investigations have determined that the noise sources of pneumatic rock drills can be classified into three areas; exhaust noise, drill steel noise and mechanical noise from the components. The exhaust noise is generated by spent air passing from the exhaust opening at high velocity and mixing with ambient air. The drill steel noise is caused by the vibration generated by the impact between the drill piston and the drill steel, also the noise of the drill steel against the rock causes the drill steel to ring. Further mechanical noise is generated by the rotation mechanism and interaction of internal parts.

While each of the significant noise sources within a conventional rock drill system has been addressed in previous papers by many researchers, few solutions have been successfully implemented. However, previous work has shown that the problems that restricted implementation of these solutions can be resolved if the thrust is directed along the axis of the drill. Noise control of existing pneumatic drills is difficult to accomplish. Factors that have to be considered are cost, performance and weight. Muffling of exhaust has been done to varying degrees for noise attenuation but is only marginally successful (15).

Objective

The report describes the procedure for the measurement and reporting of noise from portable pneumatic tools such as jackleg drills.

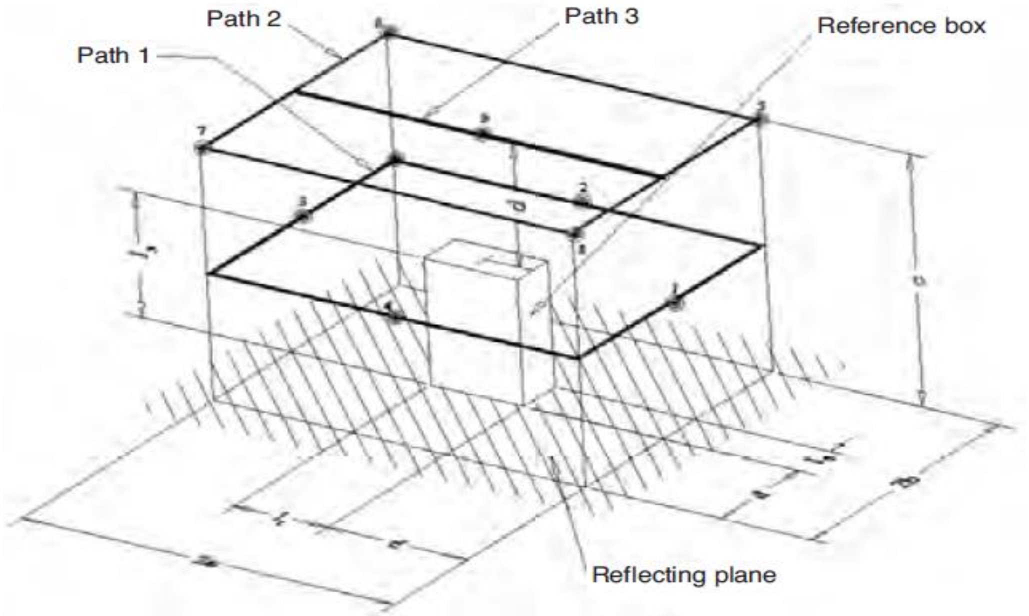
Method

The method used in this evaluation consisted of sound pressure level measurements on a surface enveloping the noise source. The acoustic environment for the measurements of the source was a free field over a reflecting pane. The measurements were then used to estimate the sound power level at each frequency band of interest.

The surface enveloping method allows for three grades of accuracy; precision, engineering and survey grades. The engineering grade accuracy was implemented in this evaluation and followed the ISO Standard 37444.

Two rock drills were tested in NOISH’s Pittsburg Research Laboratory to obtain the measurements. The two rock drills were both Seco S215 machines, the one was a standard Seco S215 while the other was the encapsulated S215 CSIR prototype, developed by CSIR Miningtek (15).

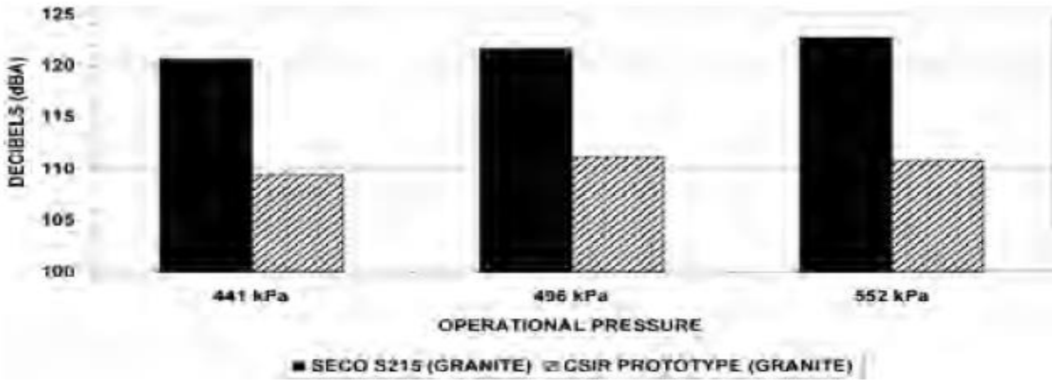
Figure 1. – Example of reference and measurement parallelepiped surfaces (15).



Discussion and conclusion

The test results are similar to previous tests carried out on the standard Seco S215 and the CSIR encapsulated prototype, however in addition to the standard test criteria this test also tested and recorded the sound power levels at three different air supply pressures. The outcome of the tests indicates that the best penetration rates were achieved at the manufacturers recommended air supply pressure of 496 kPa for the standard Seco S215 and at an increased pressure of 552kPa for the CSIR encapsulated type. The sound power levels increased on both the standard and encapsulated type rock drills when the supply pressure was increased. It was furthermore found that the CSIR prototype was too difficult for one person to operate and would take too long to set up underground.

Figure 2. – Performance comparisons while drilling in granite (15).



An examination of methods whereby noise levels in current and new mining equipment may be reduced (SIMRAC GEN 420, A. Maneylaws, G. Norman & F.H Glehn – December 1997 – Reference report PR 99-0382 CSIR) (6)

Summary of paper

The document is an extensive review of international work on mining equipment noise controls that have been carried out (mainly completed in the 1970s and 1908s). The sources of noise on percussion rock drills, continuous miners, dust scrubbers and fans, long wall machinery and trackless vehicles were identified. Noise control techniques, for retrofit and for incorporation in new equipment are proposed and noise reductions costs quantified.

Hand held Rock dills

Drilling noise is the sum of three major noise sources: -

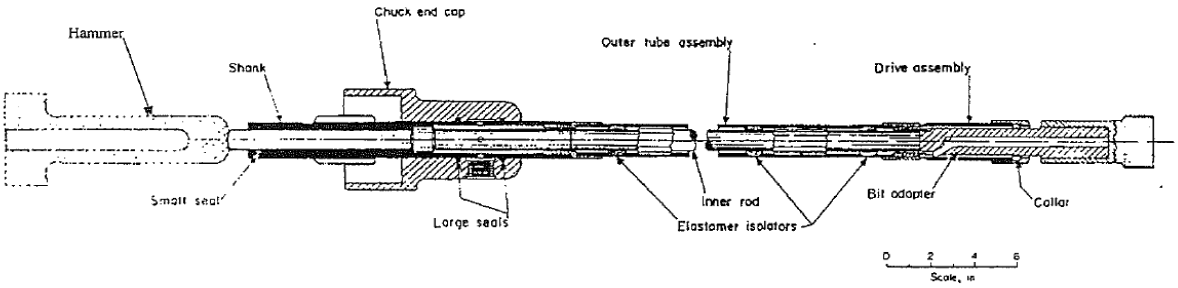
- Exhaust noise (absent in hydraulic drills)
- Drill steel
- Drill body noise

Drill steel noise results from transverse and longitudinal vibrations of the rod.
Drill body noise is produced by moving and impacting parts inside the drill exciting the drill body and becomes apparent only when exhaust noise and drill steel noise have been reduced significantly.

Noise reduction techniques include exhaust mufflers, drill body enclosures, constrained layer damping collars and sheaths and concentric drills. Reference is made to the development of the silent rock drill (encapsulated) of which the prototype was still to be completed.

From the research done it was found at the time that concentric drill steels had reduced sound power levels and were a viable alternative to conventional drill steels. The concentric drill steel reduced the mid frequency noise significantly but increased the noise at frequencies of 8000 Hz and above (15).

Figure 1. – Concentric drill steel design



Retrofit summary on hand held rock drills

The following are simple treatments which are either well proven or readily available or which have been shown to be reasonably effective but have not been widely employed in the field (15):

- Fitment of wraparound muffler — 7 – 10 dB (A) reduction
- Constrained layer damped drill steel (collar) With wraparound muffler. — 10 -12 dB (A) reduction
- Constrained layer damped drill steel (full length) With wraparound muffler. — 10 – 15 dB (A) reduction
- Shrouded drill steel with wraparound muffler. — 10 – 15 dB (A) reduction.

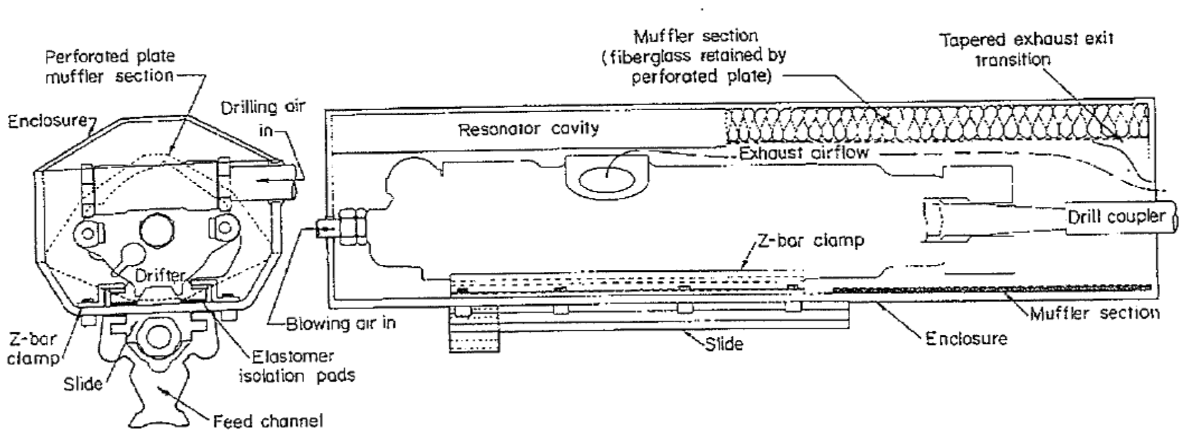
Boom mounted rock drills

As with hand held drills, the three major sources of noise on pneumatic, boom mounted drill rigs are the exhaust, drill steel and drill body. Exhaust noise reduction techniques have included piping the exhaust away from the operator, attaching a muffler to the exhaust port and placing the entire drifter inside an acoustic enclosure (15).

Retrofit treatments for boom mounted rock drills

A workable retrofit was developed under contract for the acoustic enclosure for boom mounted rock drills. The top half of the enclosure hinged open from the bottom half, allowing easy access to the drill (15).

Figure 2. – Retrofit drill body enclosure



Retrofit summary

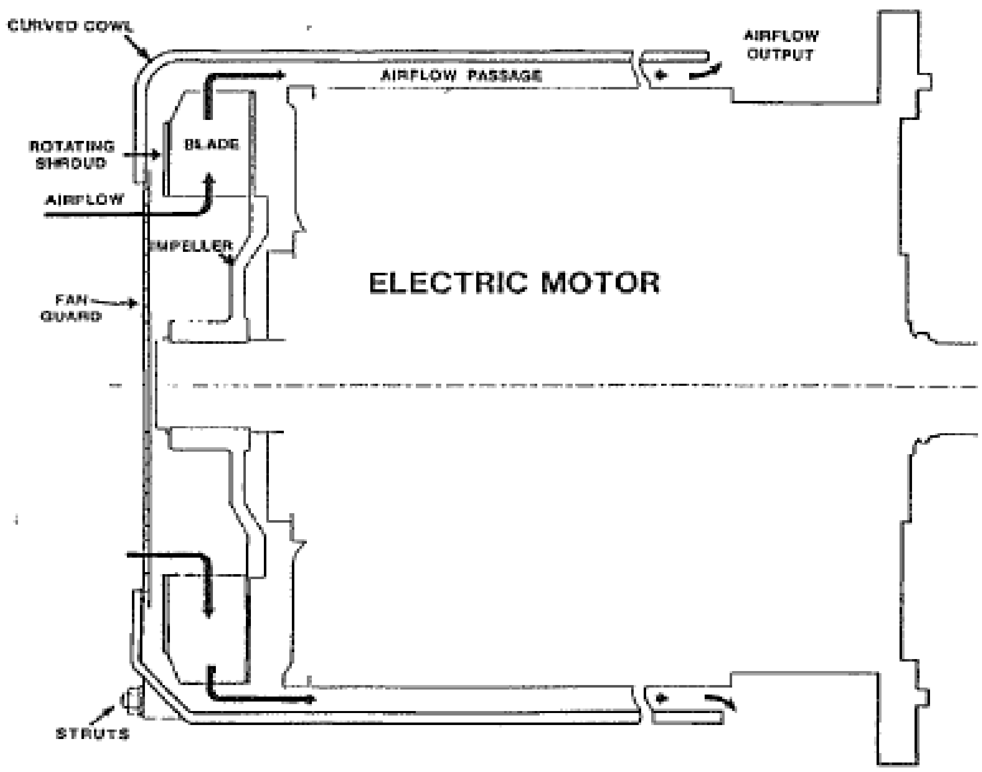
The development of drill shroud tubes (including collapsible shroud tubes) should be perused. Acoustic cabs are available from some manufacturers and should be considered as an option where they are acceptable in an underground situation.

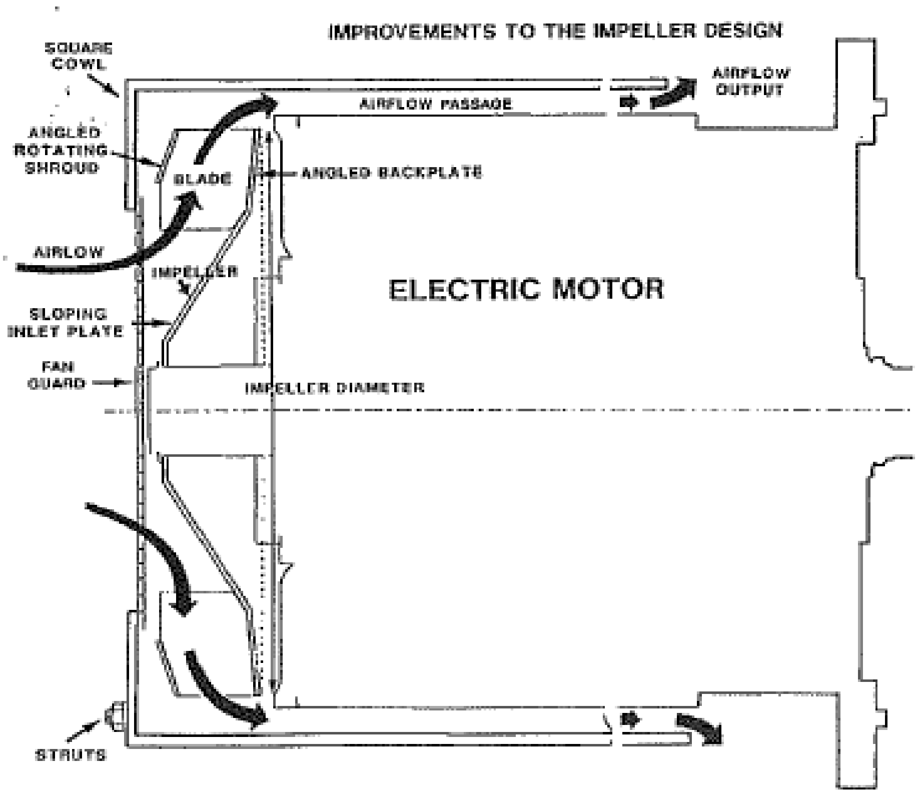
• Drifter muffler	4 – 8 dB(A)
• Drifter muffler with drill steel shroud	8 – 12 dB(A)
• Drifter muffler with constrained layer collar	8 – 10 dB (A)
• Addition of acoustic cab.	30 – 40 dB(A) (15)

Electric Motors

On electric motors the cooling fan is often the main source of noise, producing broadband noise and discrete frequencies. Straight bladed bi-directional fans are the noisiest types. Fairly simple redesign or use of curved blade unidirectional impellers can effect reductions of 5 – 10 dB(A) (16).Further noise reductions are possible with silencers on the inlet and outlet. As the rotor rotates magnetic noise produces many discrete frequencies. It is a function of the number of rotor and stator slots, the flux density of the magnetic field, the coil winding and the size of the air gap. Magnetic noise should be minimized at the design stage, but can sometimes be problematic in cases where insufficient care has been taken in the design (6).

SECTION THROUGH FLP MOTOR SHOWING AIR COOLING COMPONENTS





The two above sketches indicate the before and after changes made to an electric motors cooling fan as a noise control re-design.

Jet fan and auxiliary fan noise

Auxiliary fans are usually free standing/ suspended and typically in the order of 11kW. Likewise, the auxiliary fans which range from 4kW up to 75kW are generally less significant in terms of personal noise exposures since personnel working in the stope face are some distance from the fans. Ducted fans can generally be located at positions where there are no personnel permanently stationed. Silencing may not be required on the ducted side if rigid ducting of more than 30 to 40 meters is installed, since noise decay occurs along the ridged ducting (6).

- Fan absorptive silencers
  Fan manufacturers supply both off the shelf and custom designed fan inlet and outlet absorptive silencers. It is calculated that effective absorptive silencers fitted to both inlet and outlet ends of a scrubber unit would reduce fan noise levels by up to 11 dB (A). The length and bulk of such silencers may, however be an operational problem, particularly with the outlet silencer being prone to damage (6).

- Fan reactive silencers
  The development of prototype reactive silencer elements for underground fans formed part of a coal and steel community research project in Europe. Reactive silencers were studied in an effort to obviate the potential contamination by dust and water of absorptive silencers. Testing the reactive elements gave reasonable attenuations of 5 – 10 dB (A) at lower frequencies but no significant attenuation above 1 Hz (6).

- Fan active noise control

  The basic concept of active noise control is the cancellation of an existing noise by the creation of an “anti-noise” of the same amplitude and frequency as the offending noise but exactly at 180° out of phase.

  Active noise control is now a well proven solution to many low frequency noise problems associated with fans and compressors in general industrial applications. Advantages of active attenuation are in the reduction of low noise, particularly tonal noise, and in the reduced pressure drop of the system compared with absorptive silencers with splitters or center pods. The fan blade passing frequency tonal components of the noise produced by scrubbers would seem to be the ideal target of cancellation by active noise. However, current disadvantages of active attenuation are in the length of duct required, the intrinsic safety aspect of the electronics system and the initial capital costs (6).

- Fan re-design/ modifications

  If the blade tip clearance could be reduced the fan efficiency would increase, allowing the fan to be run at a lower speed and thereby reducing the fan noise level. Thus, a reduction in blade tip speed of, say 25% would result in a reduction in fan noise of between 6 and 10 dB (A). In terms of minimizing blade tip clearance fan casings can be manufactured with abradable blade track linings.

  There are several design considerations which can led to reduced noise exposure with regards to axial fans. Guide vanes downstream of the impeller improve the pressure development and efficiency but, can also have a detrimental effect on noise levels. The design and positioning of downstream guide vanes should be examined for reduced noise potential. Bifurcated fans are very inefficient, possible development of an external motor, out of the airstream and incorporating a right-angle gearbox drive would be worthy of consideration. The gearbox could be used to vary fan speed, which at present is defined by either the two pole or 4 pole motor speed (6).

Trackless vehicles

Extensive measurements of noise from diesel powered mining equipment have shown levels at the operator’s position of over 100 dB (A), with corresponding mean noise exposure levels of 99 dB (A). In this type of equipment, the engine generally constitutes the major source of noise. The engine noise comes from the exhaust, the intake and the casing, the cooling fans can also be a significant source of noise, as can be the transmission, drive train and hydraulic system(6).

The application of standard noise control techniques is very effective in quieting this type of equipment. Practical and economic considerations generally do not permit modification to the primary noise sources. Full enclosures are the best means of blocking the radiation of noise from engines and transmissions. The effectiveness of an enclosure increases with the surface density of its walls and can be enhanced if the interior surfaces of the enclosure are faced with acoustically absorptive material. Partial enclosures or barriers can be used where cooling and/ or access requirements do not allow for full enclosures. This is considerably less effective because of sound propagating out of openings, although their performance can be enhanced by lining with acoustically absorptive material. Reactive silencers or mufflers are used to reduce engine exhaust noise. Mufflers should be matched to the particular engine so that it is acoustically effective but does not produce excessive back pressure (6).

Trackless machine recommendations

Manufacturers can supply vehicles with engine and transmission compartments lined with acoustic absorptive materials. Care should be taken to ensure that all unnecessary openings in these compartments and in the operator's compartment with acoustic absorbent (6).

Retrofit summary

Engine and transmission compartment lining kits can be fitted to existing equipment in the mine workshops. Care must be taken to seal any unnecessary gaps in the compartments and to reduce the excitation of body panels by the use of neoprene gaskets on covers.

- Engine/ transmission enclosures and operators — 5 – 12 dB(A)
  Compartment treatment with acoustic absorbent
  Exhaust muffler.
- Addition of an acoustic cab — 12 – 20 dB(A) (15)

Procurement procedure and noise test data for new equipment

References to long term reduction which should include "Procurement Policy" which makes sure that noise is taken into account when selecting new machinery. The reference also includes requirements for Noise Test and Measurement procedures, the prescription of measurement and test instruments and the requirement for a "Standard Noise Data Base" (6)

Noise control in underground metal mining (NIOSH - IC 9518 circular, Efrem R. Reeves, Robert F. Randolf, David S. Yantek and J. Shawn Peterson) (17)

Summary of paper

The circular is an information booklet published by NIOSH (Department of Health and Human sciences) in the USA, the booklet gives detailed explanation on what the following are:

- Noise induced hearing loss
- Variables of noise exposure
- Noise problem analysis
- Noise dosimeters
- Sound levels, and
- The hierarchy of noise control.

Test work performed

The area that looks at the actual noise control in underground metal mining and upon which test work was conducted covers the following equipment types;

- Load haul dumpers (LHD)
- Haul trucks,
- Jumbo drills, and
- Jumbo bolters (17).

It is noted that all the field studies conducted where on the older generation equipment types that consisted of vehicles with open cabs and open engine compartments. Which is relatively far from where we are today, though some of the older, less intensive and cash strapped mining operations may still be using these Trackless Mining Machines. The field studies looked at barriers and sound absorbing materials for engine enclosures, operator cabs and covers for motors.

A point of interest that is covered in the various noise reduction test work, is that they found that 6mm conveyor belting provided greater noise reduction levels than fiberglass blankets or thick quilted fiberglass absorptive material. It was also found that noise reduction improved when the material was mounted with an airspace between it and the surface behind it. To achieve the best results, the material was spaced “One-Quarter Wavelength” from the surface behind it. In this case, the wavelength is based on the lowest frequency of interest (17).

Where: $t = \lambda/4$
T = material thickness, (inches)
λ = Wavelength of sound for lowest frequency of interest (inches)

When using the above equation, it must be noted that in some instances it can be impractical to install material with optimal thickness or spacing to absorb low frequency sounds.

The table below has been included to illustrate the increased noise reduction when using conveyor belting rather than your more expensive conventional type sound absorbing materials (17).

Motors	Noise control	Without control (dB[A])	With control (dB[A])	Noise reduction (dB[A])
Bolter 1	0.25-inch-thick heavy conveyor belt	84.9	83.2	1.7
Bolter 2	1.5-inch-thick fiberglass blanket	77.3	76.9	0.4
Face drill 1	0.5-inch-thick heavy conveyor belt	79.4	77.2	2.2
Face drill 2	1.5-inch-thick quilted fiberglass absorptive material	79.9	79.5	0.4
Face drill 3	0.25-inch-thick Plexiglas	84.3	81.9	2.4

Conclusion

Through evaluating different noise controls on underground machinery, NIOSH researchers discovered several findings. Both the effective and ineffective treatments rendered valuable information.

- Although it is tempting to use sound-absorbing materials for noise controls because they are inexpensive and simple to attach to existing surfaces, sound barriers were always more effective in the examples NIOSH studied for this report.
- Windshields and environmental cabs can be highly effective noise controls, especially for high frequency noise.
- Creating an airtight seal in machine panels can greatly enhance the noise reduction benefits of existing barriers.
- Gaps in barriers compromise noise control effectiveness.
- When openings in enclosures are necessary, a partial enclosure can provide some benefit. Enclosures should be lined with an absorptive material thick enough to absorb the dominant sound frequencies. Openings to let air in and out of the enclosure should have lined ducts with multiple bends to absorb sound and to force it to follow a circuitous pathway before exiting the enclosure.

<u>Noise controls for mining equipment (SIM 12-05-01 Noise Controls for mining environment – RC Kroch, RW Otterman and PS Heyns – 30 June 2014) (18)</u>

<u>Summary of paper</u>

Past research work undertaken on the SIM 05-05-01 project covered preliminary work on the following areas:

- Development of a methodology for noise reduction on mining equipment
- Construction of prototype silencers for a demonstration scrubber
- Development and demonstration of an above-ground noise measurement standard
- Development of an underground noise measurement standard
- Development of a methodology for prediction of underground noise level.

(This work was described in the report "Noise controls selection and design methodology for mining equipment" (Eksteen & Botha 2012)) A specimen on which to apply the principles contained in SIM 05-05-01 was required, and a scrubber was selected in that project. This project aimed to expand the work done in the SIM 05-05-01 project on the scrubber specimen with the following objectives:

- Experimental evaluation and of the application of the developed methodology for the design of noise controls for mining equipment
- Demonstration and application of the developed standard for underground noise measurements
- Projection of underground noise measurements (18).

In fulfillment of these objectives, a number of measurement campaigns were undertaken, both above ground and underground. These measurements formed input and verification parameters for the projection of underground noise levels, to evaluate the standards developed in SIM 05-05-01. Furthermore, acoustic measurements were done above ground to determine acoustic factors such as direct field and sound power to predict the underground noise. The noise was then measured underground to validate the findings. An acoustic point source (for methodology verification), scrubber and silenced scrubber were measured underground. The finite element model often over predicted the sound level by between 5 – 7 dB. This figure improved significantly when measurements in the acoustic far field were considered, where an accuracy of less than 4 dB were the norm (18).

Initial silencer design (SIM 05-05-01) sound power level results

- Reduced from 116.3 dBW unsilenced to 105.0 dBW with first generation silencing.
- Reduced from 116.3 dBW unsilenced to 101.7 dBW with second generation silencing.

The sound power consequently reduced form 0.4W to 0.031W to 0.015W (for the unsilenced, first generation silencers and second generation silencers respectively) (18). Furthermore, acoustic measurements were done above ground to determine acoustic factors such as direct field and sound power to predict the underground noise. The noise was then measured underground to validate the findings (18).

An acoustic point source (for methodology verification), scrubber and silenced scrubber were measured underground. The finite element model often over predicted the sound level by between 5 – 7 dB. This figure improved significantly when measurements in the acoustic far field were considered, where an accuracy of less than 4 dB were the norm (18, 19).

Discussion

The project commenced with the legacy of SIM 05-05-01:

- Above ground measurement standard
- Underground measurement standard
- Proto-type silencers, developed according to the noise controls for mining equipment
- Prediction of underground noise methodology.

Firstly, this step provided data to gauge the effectiveness of the scrubber. This was in the form of sound power, sound pressure level (SPL) contours around the scrubber, and a sound intensity field. The direct field around the scrubber was also measured with the aid of sound absorbing material placed on the ground (this eliminated ground reflected sound). In addition, this data provided guidance on how to improve upon the silencer design (18).

Secondly, the data could be used as input to the FEA model, used for the projection of underground noise. Parameters in question were the direct field sound as well as the sound power. Both these quantities were used in “one third” octave form. The above ground standard was also applied to an acoustic point source, designed by Business Enterprises at University of Pretoria. This point source, using the gathered and processed data, was used to validate the underground noise prediction methodology. The paper describes and includes numerous graphical representations of the sound intensity level field around the scrubber for both silenced and unsilenced tests inclusive of the overall “Sound Power Level” contours at various distances/ radius from the test installation (18).

Further to this the graphical representation of the sound power is plotted against the center frequencies. In addition to the standard testing and plotting of sound power levels, the “Acoustic point source” was determined through finite element analysis (FEA). Due to the point source emitting sound uniformly in all directions, results were based on radius from the source (18).

Recommendation

The standards that were developed through SIM 05-05-01, especially the above ground standard, can complement the “buy-quiet” policy common to many mines. As the standard recommends the type of measuring equipment for use, to the required measuring protocol, to the mathematics required to compute certain parameters; the standard can empower mines and original equipment manufacturers (OEMs) to acoustically compare various types of equipment in a standardized manner (18).

Likewise, the OEMs can use methodology for silencing of mining equipment as a guide to designing equipment to be quieter.

Regarding the noise prediction methodology, it is possible to create a software package or lookup tables for underground noise based on the following parameters:

- Underground chamber geometry
- Sound power of the machine(s) in question
- Bystander location (18)

Considering the large range of values that the above variables can adopt, it is likely that a software package may be the more modern and intuitive to approach.

Conclusion

As the standard recommends the type of measuring equipment for use, to the required measuring protocol, to the mathematics required to compute certain parameters; the standard can empower mines and “Original Equipment Manufacturers” to acoustically compare various types of equipment in a standardized manner. Likewise, the “Original Equipment Manufacturers” can follow the standard developed for use as a methodology for silencing of mining equipment, and could be used as the standards being referred to in the “Procurement Policy” as a guide to designing equipment that would comply to the mining industry “buy-quiet” requirements, which would furthermore assist the mining industry in meeting the milestones.

Regarding the noise prediction methodology, it is possible to create a software package or lookup tables for underground noise based on the following parameters:

- Underground chamber geometry
- Sound power of the machine(s) in question
- Bystander location

Considering the large range of values that the above variables can adopt, it is likely that a software package may be the more modern and intuitive to approach.

<u>The attenuation of rock drill vibration (SIMRAC GAP 634 – JPD Strydom – August 2000) (20).</u>

<u>Summary of paper</u>

The paper discusses “Vibration Transfer” from the rock drill handle to the operator’s arm, and though frequency levels are discussed and the attenuation thereof, it is in relation to the mathematical calculation of forces transmitted through vibration. The paper focuses on the damping of vibration transfer and the design changes of the rock drill operators handle to incorporate a damping system. The principal should not be discarded based on the fact that it is not a “Noise Reduction” study, the principal should in fact be looked at from a view point in assisting with noise reduction which is caused through vibration on most equipment types (20). It is as noted in “Noise Controls for mining equipment” (SIM 12-05-01) that vibration is a contributor to noise emissions. Vibration as a noise source and the treatment thereof through balancing of the equipment is not addressed as an area of concern through “Individual” research, consideration should be given to vibration noise sources (20).

Analysis of a mechanism suspension to reduce noise from horizontal vibrating screens (NIOSH – David S Yantek and M. Jenae Lowe – 2011) (21).

Summary of paper

A-weighted sound levels around vibrating screens in (coal) preparation plants often exceed 90 dB. The National Institute for Occupational Safety and Health (NIOSH) is developing noise controls to reduce noise generated by horizontal vibrating screens. Horizontal vibrating screen noise is dominated by sound radiated from the screen body.

NIOSH researchers analyzed a mechanism suspension system that could reduce screen body-radiated noise. A finite element (FE) model of the entire screen was used to analyze the screen with the added mechanism suspension. The spring rates for the mechanism suspension were tuned to transmit vibration at the mechanism operating speed while attenuating vibration transmitted from the mechanisms to the screen body at frequencies above 100 Hz (21).

The FE results were used to estimate the A-weighted sound power level radiated by the screen sides and feedbox for various mechanism suspension spring rates. The results indicate that a tuned mechanism suspension could reduce the A-weighted sound power level radiated by the screen body due to gear and bearing forces inside the mechanisms by 7 to 18 dB (21).

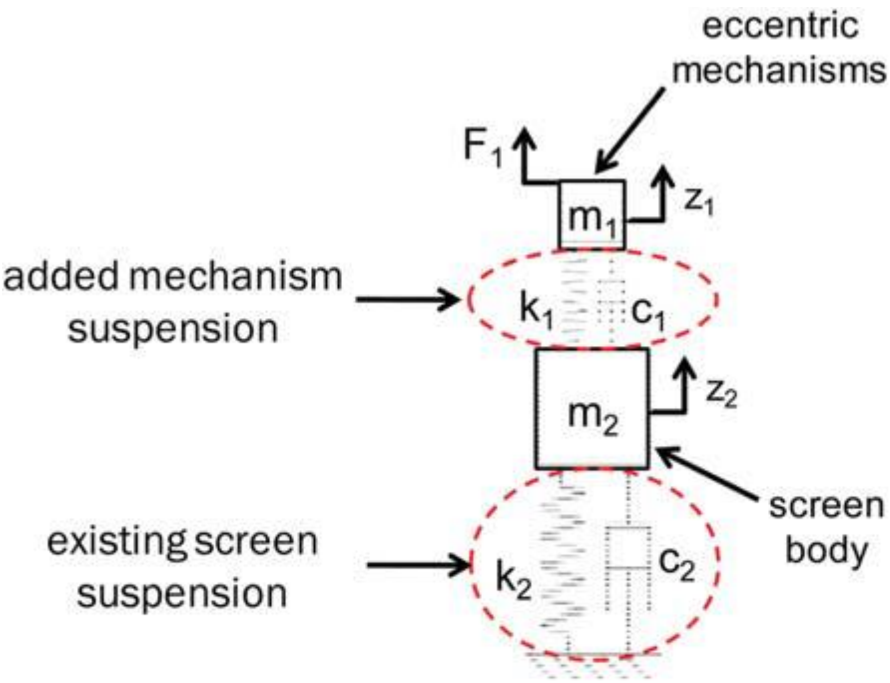
Discussion

Prior to designing a mechanism suspension, it is necessary to analyze the dynamic behavior of a screen with an added mechanism suspension. First, a two degree-of-freedom (DOF) model was used to examine the rigid body behavior of the system. Next, a finite element (FE) model of the screen with an added mechanism suspension was used to examine how the natural frequencies and mode shapes of the system vary with the stiffness of the mechanism suspension. The FE model was then used to perform a forced response analysis on the screen due to forces input at the vibration mechanisms. Finally, the results from the forced response analysis were used to estimate the sound power level radiated by the screen sides and feedbox(21).

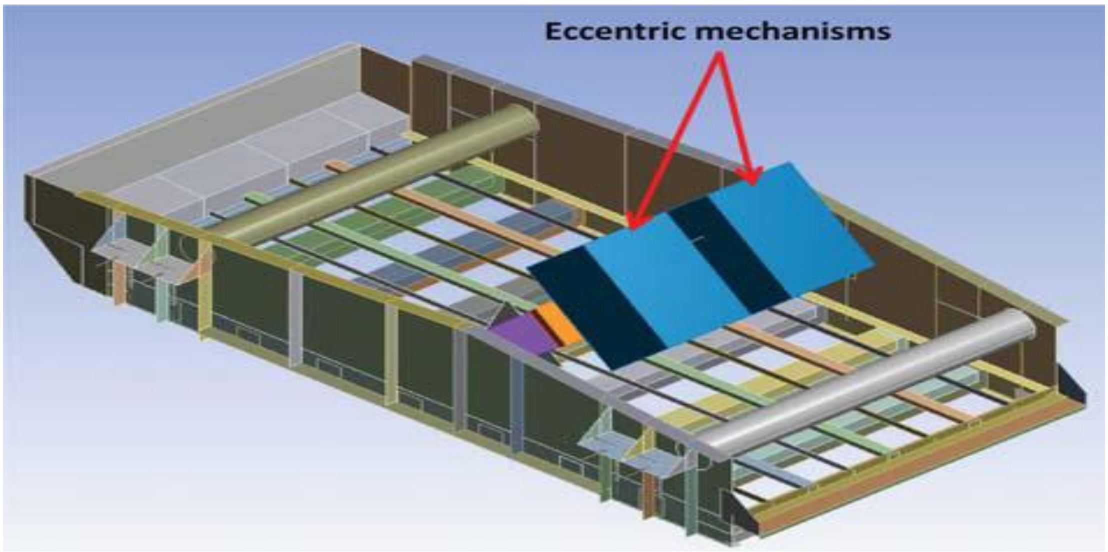
A mechanism suspension is proposed to be added to the screen to reduce noise radiated by the screen body due to gear and bearing forces within the vibration mechanisms. To add a mechanism suspension to the screen, vibration isolators would be inserted between the vibration mechanisms and the H-beam.

The vibration mechanisms would be mounted on top of a large steel plate, or raft. Then, the raft would be mounted on top of the vibration isolators. The goal of adding a mechanism suspension is to separate the primary source of mechanical energy from the noise-radiating structure, but without degrading the performance of the screen (21).

A Simple two – DOF model used to analyze the screen with an added mechanism.



An FEA model of the vibrating screen with an added mechanism suspension system

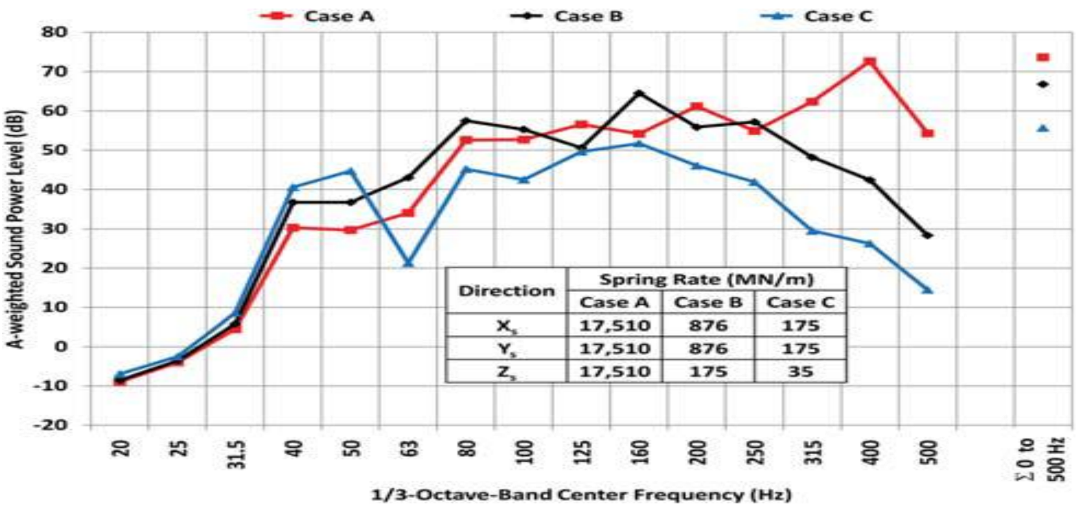


Results

Because the DOF model has two degrees of freedom, there are two natural frequencies and mode shapes for the model. In the first mode, the vibration mechanisms and the screen body move in phase with the same amplitude. For the second mode, the vibration mechanisms and the screen body move out of phase with each other, and the amplitude of the vibration mechanisms is approximately seven times that of the screen body. Because the second mode gives the appearance of the vibration mechanisms bouncing on top of the screen body, this mode is referred to as a “bounce mode” (21).

The two-DOF-analysis results showed that when the bounce mode was in the range of 50 to 70 Hz, the mechanism suspension attenuated the forces transmitted from the vibration mechanisms to the screen body above 100 Hz. In addition, the mechanism suspension did not significantly change the force transmitted from the vibration mechanisms to the screen body at the operating speed of the screen, 15 Hz. For subsequent analyses, the goal was to determine the mechanism suspension spring rates required to yield a bounce mode between 50 Hz and 70 Hz, without creating problems caused by pitching modes of the suspension. The two-DOF analysis provided good insight into the behavior of the proposed suspension (21).

In order to develop a successful mechanism suspension, the suspension's rotational stiffness about its y-axis must be increased to push the pitch mode far above the screen's operating speed. If this is done by increasing the mechanism suspension spring rates, the bounce mode of the suspension will be forced out of the 50 to 70 Hz range, and the resulting suspension will not begin to attenuate forces transmitted from the mechanisms to the screen body at 100 Hz. Therefore, instead of increasing the mechanism suspension spring rates, the distance between the suspension spring locations could be increased. This would also require the depth of the H-beam top flange and the depth of the raft to be increased (21).



Conclusion

These systems might successfully attenuate noise and vibration above 100 Hz, but because their pitch modes would be close to the screen's operating speed, these systems could cause undesirable behavior during screen start-up, shutdown, and steady operation.

The analysis revealed several important factors to consider in the design of a mechanism suspension for vibrating screens. First, to attenuate noise at frequencies above 100 Hz without significantly affecting a screen's performance, the bounce mode of the screen suspension must be kept within the range of 50 to 70 Hz. Next, the spacing between the vibration isolation mount locations must be increased to force the suspension pitch mode to higher frequencies where it will not be well-excited during screen start-up, shutdown, or operation. The analysis used here showed that a suspension system with a 50 Hz bounce mode would reduce noise more than a system with a 70 Hz bounce mode (21).

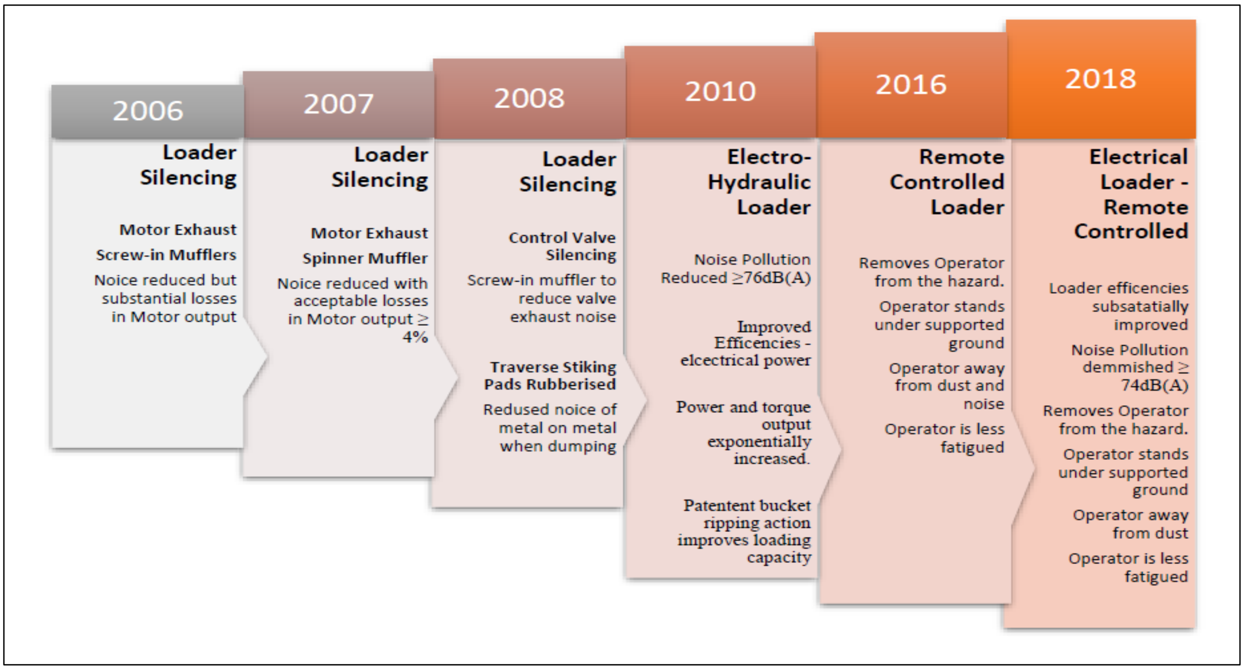
Progression of the Salzgitter Rail-bound Throw Loader for Safer, Efficient and Reliable Mining (Salzgitter Mzansi – D. McNeil – November 2017) (11)

Summary of paper

The paper was drafted to provide an insight to the Mining Industry with respect to the advancements made by the Rocker Arm Shovel Loader manufacturer, with improvement in Noise reduction and Safety in conjunction with improved efficiency. This was triggered by the Noise Milestones set by the Mine Health and Safety Council of the South African Mining Industry that no underground equipment shall exceed a sound pressure level of 110 dB(A) by December 2013. This prompted Salzgitter Mzansi to start research into reducing noise levels in their products during 2006. The paper covers the initial development of loader silencing through to the improved Electrical Remote Controlled loader.

Discussion

The Rocker-arm Shovel loader manufacturer (Salzgitter Mzansi) commenced with the development of pneumatic mufflers through the design, testing and implementation of Screw-In Mufflers and on to the complete re-design of an "Electro-hydraulic loader" and eventually on to their "Remote Controlled Pneumatic loader" and the development of their total electrical operated loaders with remote control. The newly designed "Electric" loaders have no pneumatic or hydraulic dependency and have enabled the Rocker-Arm Shovel manufacturer to reduce sound pressure levels from 114 dB(A) in 2006 to the current 74 dB(A) on their "Electric" loader (11).



Results

Salzgitter in collaboration with their subsidiary company JSN Engineering (Pty) Ltd, developed the Electro Hydraulic loader in an attempt to provide a more energy efficient, reduced noise pollution loader. The EH 300 loaders are a hydraulic close-loop system built on the principle of the pneumatic loader. The noise level test results indicated that Salzgitter had managed to reduce the loader noise level to around 74 dB(A) (11).

Salzgitter then proceeded with the development of remote operated loaders with the view to removing the operator from the direct line of noise source. This led to the design of the Remote Controlled Electro-Pneumatic (modified) version of the standard HL 380U air loader and were at the time of presenting their paper in progress of developing two new electric remote controlled loaders in the form of “Rail-Bound” and “Crawler”. Sound power level testing during the development of these loaders indicated to be in the region of 70 dB(A) (11).

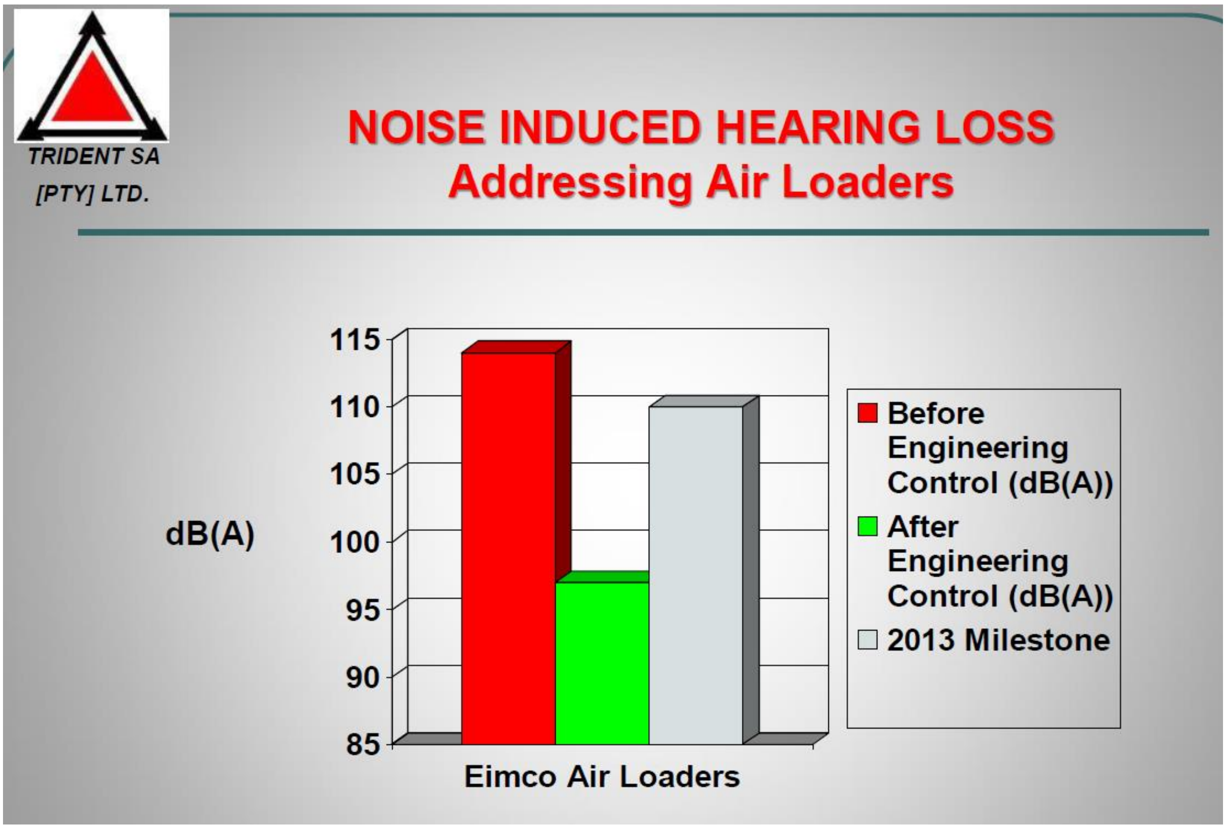
Conclusion

The paper received from Salzgitter Mzansi shows that the OEM has constantly been doing research and development to reduce the noise levels on their equipment in order to meet the industry targets. It must also however be emphasized that the Sound Power Levels were measured utilizing an instrument purchased by Salzgitter Mzansi (Quest 1900) and conducted by their own employees.

Noise Reduction Progress in Rail bound Loaders – Trident SA & Occupational Noise Survey – Trident SA (Pty) Ltd – Project No. 129/2009 (M. Calver) (9).

Summary of Presentation and Report

The presentation notes the progress made through research and development of the Eimco rocker shovel loader from the unsilenced unit in 1980 with a sound power reading of 116 dB(A) through to the silenced loader in 2007, followed by the development of the Electro hydraulic loader in 2009 and finally the development/ conversion to the full Electric Loader in 2014 with a sound power level of 62 dB(A)



Discussion

The Occupational Noise Survey conducted by Mr. B. v/d Merwe was carried out during October 2009 in the factory of Trident SA, the purpose was to determine the noise levels of the following;

- Eimco 26B Air loader
- Eimco 21B Air loader
- Atlas Copco LM 56/57 Air loader
- Atlas Copco LM 70/71 Air loader
- Lennings 215B Air loader (9)

The tests were conducted when only 1 machine was operational at a time and there were no other activities in the area. The tests were conducted in terms of the Noise Induced Hearing Loss Regulations under section 43 of the Occupational Health and Safety Act, (Act No. 85 of 1993) GNR 307 of 7 March 2003, Gauteng Noise Control Regulations of 1999 and SANS 10083: 2003 Code of Practice. A Larson Davis 831 SLM and Real Time Analyzer (Type 1), measurement microphone and piston calibrator were used. The measurement position was at the operator, where he is positioned during normal working conditions, at the air loaders controls (9).

Results

The following table represents a tabulation of each of the individual test results obtained during the testing. The figures in the tabulation have been extracted from the report (9).

	Atlas Copco LM 70/71			Atlas Copco LM57/56			Eimco 21B			Eimco 26B			Lennings 215 B		
dB(A)	Leq	Lmax	Lmin	Leq	Lmax	Lmin	Leq	Lmax	Lmin	Leq	Lmax	Lmin	Leq	Lmax	Lmin
Bottom Deck	94.5	95.9	74.0	90.8	91.4	78.0	100.7	101.4	99.4	85.0	86.3	81.5	92.9	94.5	76.3
Top deck	97.2	103.0	74.8	90.4	96.5	72.6	98.3	102.1	71.7	92.5	96.1	58.3	93.4	97.0	75.9
Combination	91.8	95.6	73.1	92.4	98.4	84.7	96.5	99.5	70.0	89.9	92.2	65.9	93.3	95.0	76.6

Conclusion

The presentation and test repot received from Trident SA (Pty) Ltd shows that the OEM has constantly been doing research and development to reduce the noise levels on their equipment in order to meet the industry targets. It must also however be emphasized that the Sound Power Levels during a phase of research and development and no further test work was submitted to substantiate the claim that they achieved 74dB(A)

Occupational Hygiene Report on Workplace Noise Assessments (Sasol Mining (PTY) LTD – Syferfontein Colliery - Trichardt) (22, 23).
(Note this paper has bearing on the Dura Fan (Axial Flow Fans) which follows on page 53

Summary of presentation

The purpose of the noise assessment was to evaluate the noise levels at various points of the section, evaluate the equipment noise levels in a section and do a comparison on noise levels between the Jet and Dura fans used by the mine.

Discussion

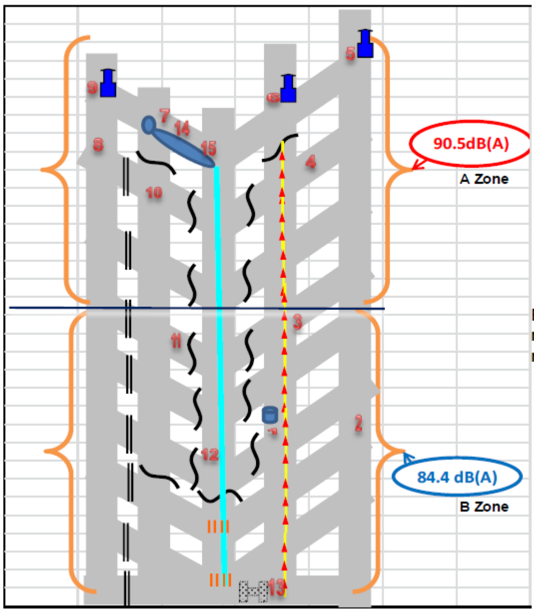
Seven different underground sections were used to carry out the comparison on noise levels, the sections tested varied in that two different underground section layouts were used during the testing.

The sound level meter was an A type 1 sound level meter supplied by Quest Technologies. The measurements were taken at positions 1 meter from the noise source and at an elevation of 1.2 meters from the footwall (22, 23).

Section 5

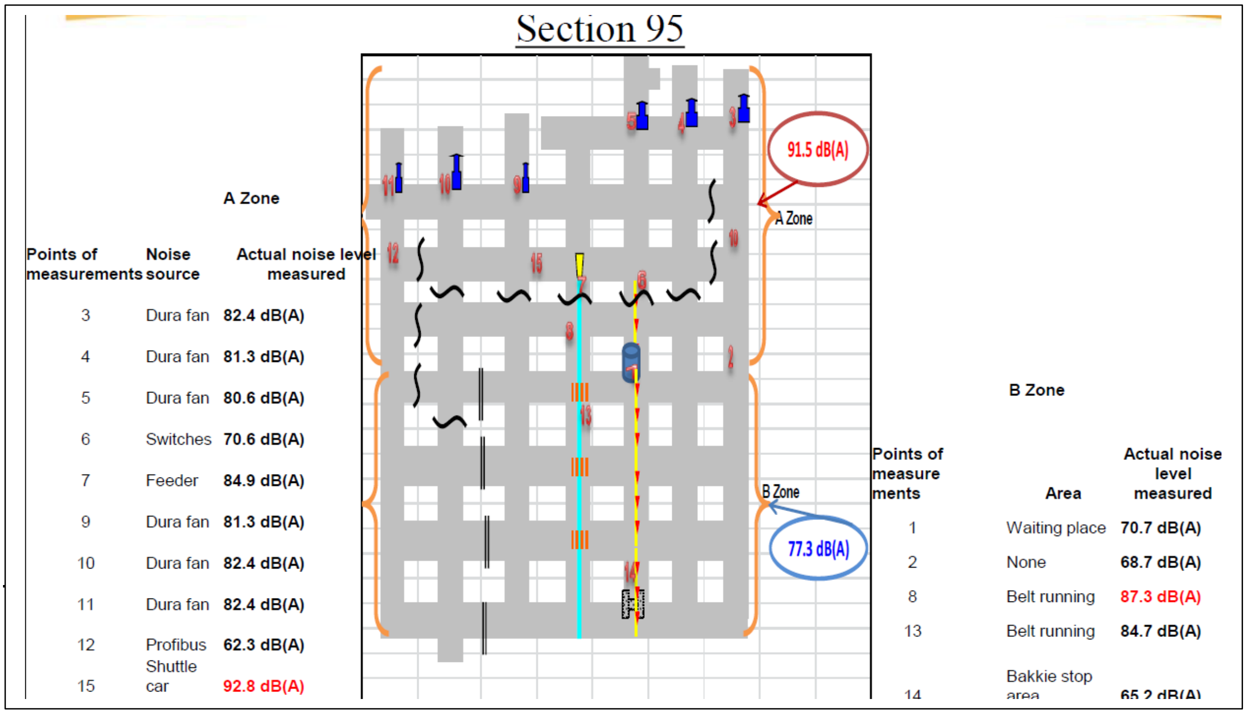
A Zone

Points of measurements	Noise source	Actual noise level measured
4	None	81.6 dB(A)
5	Jet fan	90.6 dB(A)
6	Dura fan	82.3 dB(A)
7	Voest	97.8 dB(A)
8	Profibus	81.4 dB(A)
9	Dura fan	82.6 dB(A)
10	None	80.9 dB(A)
14	Air dox	91.5 dB(A)
15	Air dox	88.7 dB(A)



B Zone

Points of measurements	Area	Actual noise level measured
1	Waiting place	80.1 dB(A)
2	None	72.9 dB(A)
3	Switches	77.9 dB(A)
11	None	75.0 dB(A)
12	Belt running	91.5 dB(A)
13	Bakkie stop area	70.4 dB(A)



Results

The Dura fans sound power levels ranged from 79.2 dB(A) to 83.5 dB(A) with an SPL log average of 82.2 dB(A) (22, 23).

The Jet fans sound power levels ranged from 88.1 dB (A) to 92.8 dB (A) with an SPL log average of 91 dB (A) (22, 23).

Conclusion

The Dura fan proved that sound power levels can be reduced and provide the same air flow and pressures when using a 4 pole motor (1480 rpm) instead of the traditional 2 pole (3000 rpm) motor when controlled with sound attenuating materials (7, 8).

Dura Fan – Axial Flow Fans (Rebeccah J. Kamp.) (7, 8)

Summary of presentation

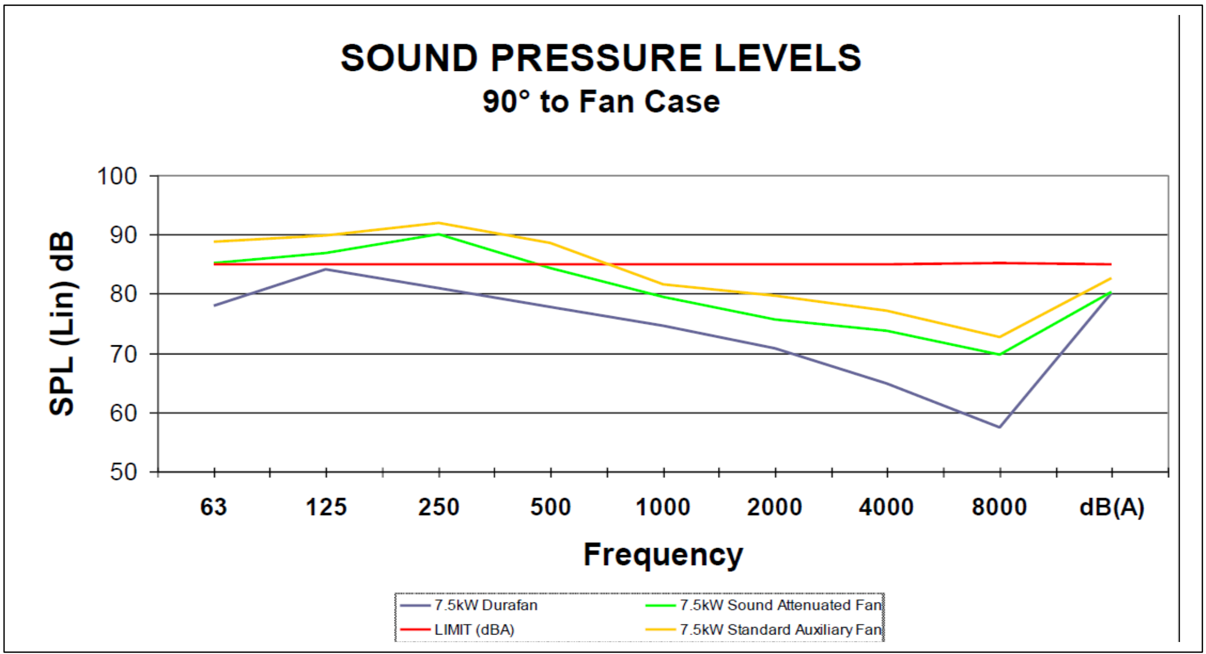
The purpose of the presentation is to show that through design research and development that it is possible to eliminate the traditional/ historical problems that are encountered when reducing the fan speed of an underground mine ventilation fan. Traditionally the use of a 4 pole motor in an underground mine ventilation fan would result in the loss air pressure, and that the 4 pole motor fan could perform equally or in certain instances better than the original 2 pole version of the same kilowatt fan (7, 8).

Discussion

The design of the fan is inherently by virtue of its duct construction an excellent channel for the transmission of noise, the ambient or environmental noise already present needs to be considered when attempting to reduce noise levels. The most effective sound damping solution still appears to be mineral wool with a perforated covering. The perforations are to an extent able to dampen frequencies based on the pitch of the holes. The open structure of the fiber allows the sound energy to travel from cell to cell resulting in noise being converted to another form of energy – Heat. It is common knowledge that a slower operating motor has a lower sound pressure level than that of a faster operating motor. The sound frequency characteristics of 2 pole motors are particular that speed motor whereas the sound frequency characteristics of a slower 4 pole motor are particular to the slower operating speed, the difference lays within the sound pressure control which is improved/ easier to control with sound attenuating materials when using the slower 4 pole operating motor (7, 8).

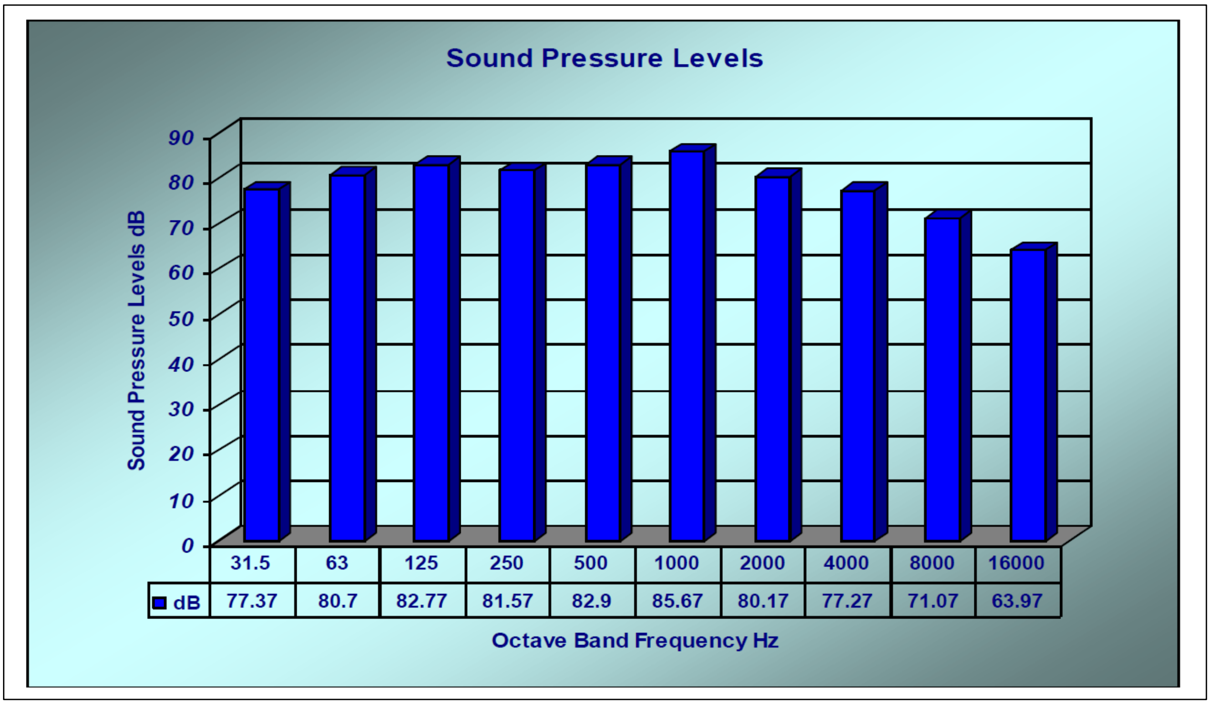
Results

Tests carried out by the manufacturer compare to those carried out via third party (users) and show a significant reduction in sound power levels. The Axial Flow fan test work can be verified through comparison to the "Occupational Hygiene Report on Workplace Noise Assessments" carried out by Sasol Mining at their Syferfontein Colliery (7, 8).

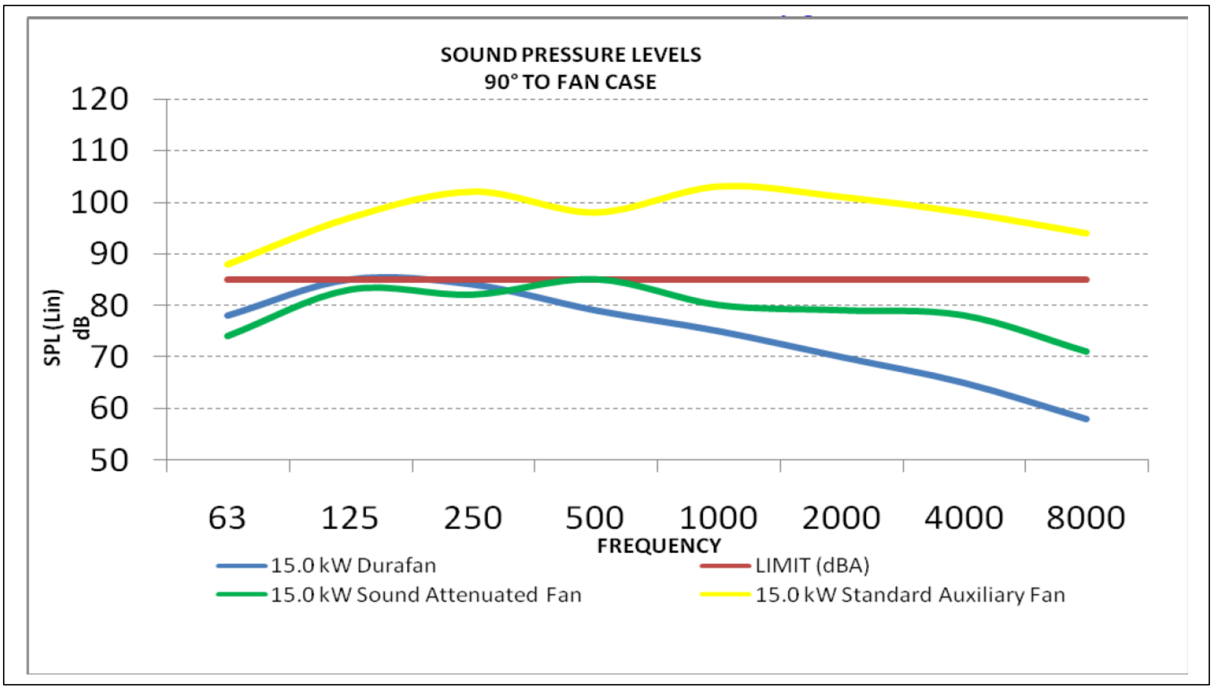


Conclusion

Similar to the Sasol Mining tests, the Dura fan proved that sound power levels can be reduced and provide the same flow pressure when using a 4 pole motor (1480 rpm) instead of the traditional 2 pole (3000 rpm) motor when controlled with sound attenuating materials (7, 8).



The figure indicates the sound power levels of a 15 kW sound attenuated auxiliary fan



The above is a comparison of sound power levels between the 15 kW Durafan, 15kW standard auxiliary fan and a 15kW Sound attenuated fan.

Electro-Mechanical Remote Operated Winch (Vincent Le Roux – JSN Engineering – November 2017) (12)

Summary of Report

The report discusses the feasibility and design attributes of the JSN Electro Mechanical Remotely operated winch, which is an improvement on the currently installed 37 kW scrapper winches installed the underground mining sections and utilized for stope and gulley scraping (12).

Discussion

The report revolves around the fact that the winch operator is removed from the immediate vicinity of the winch, this enables the operator to be out of the direct effects of noise and dust pollution, yet allow the operator to have an improved line of sight of the operation of the winch ropes and scrapper path. Standard winches were tested in both the surface test area and in the underground cubby installation. The winches that were tested on surface were those that had undergone refurbishment. The winches that were tested in the underground installed position were winches that had been in service for a duration. A calibrated decibel meter was used taking readings in a 1 m radius from the winch on the motor side. The average readings taken at the surface winch test site on the refurbished winches ranged from 85 to 88 dB(A). The same sound level tests were conducted on the winches that were installed underground in operational sites. The winches were installed in cubbies, the winch ropes were under load on the wind and unwind cycle. The average readings taken at the underground installations ranged from 95 to 98 dB(A) (12).

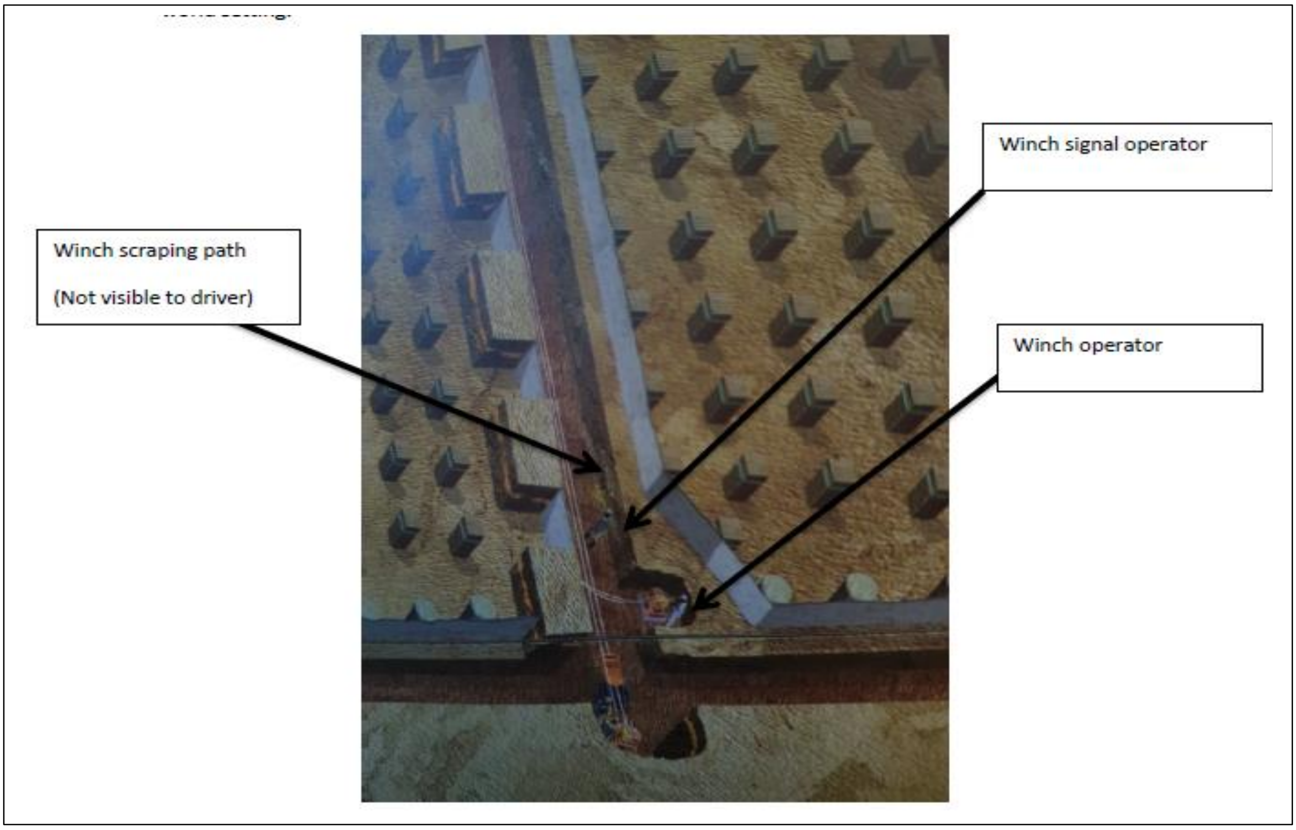


Figure denotes underground winch installations tested.

Conclusion

A newly refurbished winch has a lower sound pressure reading as a result of the open area in which it is being tested and as result on a new gear train which would emit less noise as the contact faces would be new, backlash would be less and loading would be lower with the scrapper running on a reasonably level surface.

The winch installed in the underground workings would be in a relatively enclosed area, the gears would have a degree of wear and a resultant backlash. The loading of the winch would vary with the condition of the scraper path. The removal of the winch operator from the direct operating area of the winch through remote control would reduce the operator’s exposure to the sound power levels generated in the immediate vicinity.

Noise impact study and the requirements for mitigation of the Bank No. 5 Shaft Surface Ventilation Fan – Report No. G580-R1 (Ben van Zyl) (24).

Summary of Report

The report presents the findings of a noise survey conducted at the farmhouse and of analysis that were carried out to investigate the variance of noise level as a result of noise changes in meteorological conditions. During the survey it was found that not only the Bank No. 5 Shaft Surface Ventilation fan, but that the South Shaft fan under certain meteorological conditions would also have a certain impact. The report specifies the minimum sound attenuation performance of sound attenuators required for each fan(24).

Discussion

The noise impact of the fan was determined by means of measurements conducted on 7-Dec-2005 at the Schoeman farm residence located south-east of No 5 Shaft. Sound levels (equivalent continuous A-weighted sound pressure level L_{Aeq}) were measured for the following sequence of operational conditions:

- Fan running, measure fan plus ambient level;
- Fan switched off for 10 minutes;
- Fan started up again; measure fan plus ambient level.

For purposes of evaluating the possible variance in fan noise with changes in meteorological conditions, as well as to obtain noise source data for purposes of noise control design analysis, tests were also conducted at No 5 shaft to determine the noise output (sound power) levels of the fan (24).

It was noted when No 5 Shaft fan was switched off, that there was still residual fan noise audible, albeit at a lower level. This appeared to be coming from South Shaft. To further investigate the source and significance of this noise by computer modeling, tests were also conducted at South Shaft.

The noise impact, in accordance with the principles was calculated as the difference between the noise levels measured with and without the equipment running.

All measurements were conducted in accordance with the requirements laid down in SANS 10103. The microphone was positioned at a height of 1.2 m above immediate ground level, at least 5 m away from the nearest sound reflecting surface (24).

Results

Time of day	Method	Night-time sound levels dBA		Noise Impact dB
		Ambient level	Ambient + equipment	(Increase in level)
Day-time	Measured	45	51	6
Night-time	Estimated	35	51	16
			Limit – Disturbing noise - Noise regulations	7

Table 1: Bank No 5 Shaft surface ventilation fan. Unmitigated noise impact at Schoeman farm residence (24)

Interpretation and comments:

(a) The daytime ambient sound level (fan off) measured in the survey was 46 dBA, which is practically the same as the typical level of 45 dBA given in SANS 10103 for “Rural districts” (See Table 1). The corresponding night-time level is 35 dBA.

(b) The result in Table above shows that the unmitigated day-time impact (increase in level) of fan noise measured at the farmhouse is 6 dB. The corresponding night-time impact when the ambient sound level drops by 10 dB to a typical level of 35 dBA, is 16 dB, which exceeds the regulatory limit (maximum 7 dB increase) by 9 dB. These results are valid for neutral weather conditions (Meteorological Category 4). Under worst-case conditions (Meteorological Category 6) the impact could go up to as high as 21 dB.

(c) Based on aural observation of noise at the farmhouse, the apparent source of noise was the surface fan at No 5 Shaft. Hence Anglo Coals’ brief to investigate the noise impact of the fan at No 5 Shaft. During shut-down of this fan for measurement of the ambient sound level, it was noted that despite a significant drop in noise level, a certain amount of fan noise could still be heard. At a level more or less equal to or just below the general ambient sound level, this residual fan noise was just audible above the general daytime ambient sound at the farmhouse. On closer investigation, this turned out to be noise emanating from the surface ventilation fan at South Shaft.

(d) Noise emission levels determined from measurements conducted at the two fans were used in computer modeling to study their relative contributions to the overall noise level at the farmhouse, as well as the influence of variances in meteorological conditions.

(e) It was found that No 5 Shaft fan was without any doubt the dominant source of disturbing noise. However, should noise from No 5 Shaft be reduced to an acceptable level, analyses show that the remaining noise from South Shaft will under certain meteorological conditions during night-time still cause a significant impact at the farmhouse. This is not evident at all from aural inspection at the farmhouse while No 5 Shaft fan is running, neither from measurements conducted at source. When measured at source 10 m from the perimeter of the outlet, South Shaft produces 19 dB less noise compared to No 5 Shaft. This may be misleading, because the total sound power emitted by South Shaft is only 4 to 5 dB less than that of No 5 Shaft. At ground level near the base of the outlet, noise from the outlet of South Shaft fan is directed skywards and is screened off physically by the vertical flue, while at No 5 Shaft the outlet, inclined at 45° and located close to the ground, is not screened at all. The throat is visible from the measurement point (24).

(f) As a consequence of aforementioned screening and the directional characteristics at source, noise from South Shaft will under certain atmospheric conditions (Meteorological Category 1 to 4) have negligible impact at the farmhouse. Under conditions of positive temperature gradient or downwind (Meteorological Category 4 to 6), however, the level of South Shaft noise will be only 4 to 5 dB below that of No 5 Shaft. Under such conditions, the night-time impact of South Shaft on its own would be 11 dB, which is excessive.

(g) The result in the Table above represents the unmitigated impact for the two fans running simultaneously. The specific noise impacts of each of the two fans when running individually, as determined by computer modeling for neutral meteorological conditions (Meteorological Category 4) (24), are summarized in Table 2

Fan operation	**Night-time sound levels** dBA		**Noise Impact** dB
	Ambient level	Ambient + Fan	Increase in level
No 5 Shaft only	35	50	15
South Shaft only	35	46	11
Both fans running	35	51	16
		Limit – Disturbing noise - Noise regulations	7

Table 2: Bank No 5 Shaft and South Shaft surface ventilation fans. Unmitigated night-time noise impact at Schoeman farm residence. Fans running individually (24)

Conclusion

Noise reduction requirement

(a) In terms of noise regulations, a noise which raises the ambient sound level by 7 dB or more (≥ 7 dB impact), is deemed to be disturbing. To reduce the impact to 7 dB, a reduction of at least 8 dB is required in the overall ambient sound level for No 5 Shaft fan and 4 dB for South Shaft fan.

(b) It should be cautioned, however, that the regulatory limit of 7 dB should not be interpreted as an upper limit of acceptability; it serves to define a point where measurement uncertainties and other variances have little bearing on the outcome of an assessment and where there can be no argument about the validity of complaints. In fact, SANS 10103 guidelines indicate that an increase of 7 dB is likely to have serious consequences. Hence, in noise impact assessments relating to new developments, it is unacceptable to set 7 dB increase as a design or planning target.

(c) It is therefore recommended that measures for mitigation be designed to reduce the impact to 3 dB or less. This means that the overall ambient level must be reduced by 12 dB and by 8 dB for the No 5 and the South Shaft fans, respectively.

(d) Moreover, it also needs to be taken into account that the overall ambient level is the energy-based sum of the residual ambient sound and the specific fan noise. An impact of 3 dB, i.e. an increase of 3 dB in the overall ambient noise level, arises when the specific fan noise level equals the residual ambient sound level. Specific fan noise, or noise emission at the fan, must therefore be reduced by 15 dB and 11 dB for No 5 Shaft and South Shaft fans, respectively (24).

(e) As a minimum requirement, an in-line sound attenuator has to be installed in the outlet duct of No 5 Shaft fan.

(f) Fan noise is frequency dependent. The level at the receiver is determined not only by source emission characteristics, but also by frequency-dependent losses incurred during atmospheric propagation. Moreover, each frequency band contributes to the overall dBA level in accordance with its A-weighting level.

(g) With all these factors taken into account, the minimum noise reduction requirement to achieve an overall reduction of 15 dB in noise emanating from No 5 Shaft and 11 dB for noise emanating from South Shaft as a function of frequency at octave band center frequencies, are as specified in table.

(h) Pre-mitigation baseline noise levels measured 10 m from the fan outlet duct perimeter, are summarized in Table 3.

(i) It is recommended that, in the first phase, only No 5 Shaft fan be treated for noise reduction, after which the necessity for reduction of South Shaft fan be re-assessed. It is possible that prevailing meteorological conditions will render the vertically radiating fan at South Shaft less disturbing at the farmhouse and that mitigation is not required for this fan.

(j) It is not possible in the presence of the high levels emitted from the outlet, to what extent breakout noise from the motor room or ducting currently contribute to the total noise level, but one would expect and all indications are that it is negligible compared to noise from the outlet. The need for additional screening of breakout noise, if significant, should be assessed upon installation of the attenuator in the first phase (24).

Sound attenuation

Fan	Minimum octave band sound attenuation dB						
	Octave band center frequency Hz						
	63	125	250	500	1 000	2 000	4 0000
No 5 Shaft	0	4	14	18	17	5	0
South Shaft	0	0	10	14	13	0	0

Table 3: Anglo Coal No 5 Shaft & South Shaft surface ventilation fans. Sound attenuator requirement. Minimum sound attenuation dB (24)

The supplier shall establish whether the required length of attenuating elements will require a vertical extension of the outlet duct.

Wright 356 Load Haul Dumper – Upgrade Requirements for Noise Control (Goedehoop Colliery) (Ben Van Zyl – Acusolve – Report G503-R1) (25).

Summary of Report

Goedehoop Colliery commissioned Acusolv to develop engineering solutions and specifications to reduce the A – weighted (dBA) noise level in the driver’s cabin of the Wright 356 load haul dumper (LHD) to less than 85 (dBA), alternately to reduce the noise level in the driver’s cabin to the lowest possible level within practical limits within reasonable costs.

The investigative tests were in manor used for the purpose of noise zoning, the tests were purely for the purpose of design and reference. Noise levels were measured at a distance of 1000 mm from the engine and at the actual driver’s ear. Averages were taken over short periods at which time the engine was running without load at constant speeds (25).

It was also deemed necessary to check the reverse alarm noise with respect to hearing safety. It was found that the alarm on its own produces an average level of 77 (dBA) at the driver. The reverse alarm has practically no effect on the total noise level and from the tests it was evident that the reverse alarm had no impact on the driver’s hearing.

Considering that reflection and reverberation in confined spaces such as a tunnel may elevate the noise level by between 3 and 6 dB and the engine load may add another 3 dB. When considering the averages that were taken over the short periods of time while testing at constant speeds with no load, it is estimated that the noise level to which the driver would be exposed over an 8-hour rating $L_{Req\ (8\ hour)}$ of up to 102 (dBA) under typical operating conditions (25).

Discussion

When considering the frequency characteristics most of the noise energy appears in the medium to high frequency range, but the A-weighted spectrum also showed two strong components in the low frequency range, in the 200 and 259 Hz third octave bands (25).

Figure 1 shows the third octave frequency spectrum of engine noise in the driver’s cab. The LIN spectrum represents the actual linear sound pressure levels, while the A-weighted spectrum represents the levels weighted with the frequency sensitivity characteristic of human hearing.

The A-weighted levels are used in the calculation of the (dBA) level and the values represent the contributions of each third octave band to the overall loudness or impact on hearing.
The A-weighted is therefore more significant than the linear levels when considering the measures to be taken for the design purpose of noise reduction (25).

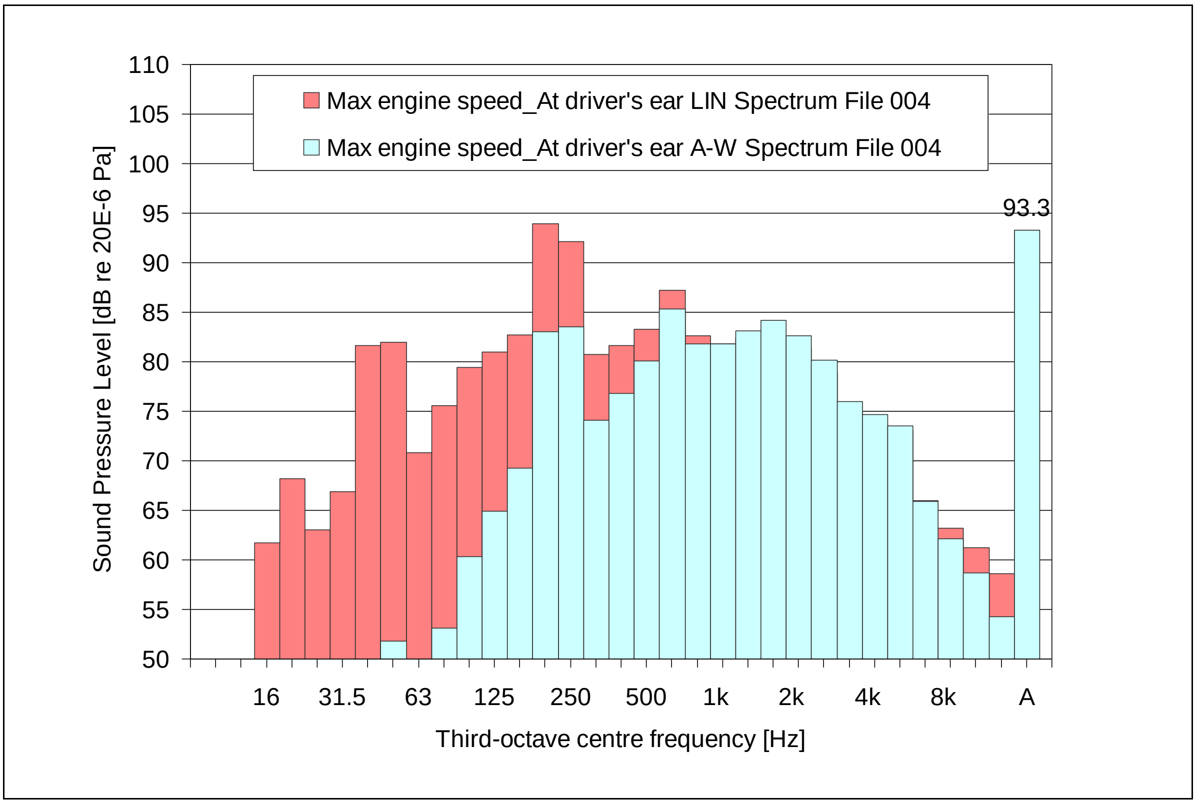


Figure 1

356 Wright Load Haul Dumper before upgrade. Typical Linear and A-Weighted frequency spectra of noise in driver's cabin at Maximum engine speed (25).

The strategy for noise reduction entailed;

- The screening off of the engine noise by fitting a ventilated noise hood to the engine.
- Partially screen off noise at the driver by fitting safety glass on two sides of the driver's cabin.
- Treat the roof of the driver's cabin with acoustic absorption to counteract reverberation and noise build-up as a result of "partial" enclosure (25).

Although not considered as a practical option in the Wright 356 Load Haul Dumper, it should be noted that air-conditioning would allow much more effective sound proofing of the cab. This should be a principle requirement for low noise design in new TMM machines. The hood was tailor made to achieve the best fit and comprised of a left and right side components. The hoods on either side of the engine are semi-closed with acoustically controlled ventilation openings and designed such that they are completely demountable for maintenance purposes.

The hood fully encapsulates the engine top, with the sub-frame comprising of two of six main sides. A supporting steel framework is fabricated to suite the application and bolted to the LHD sub frame. The acoustic panels are then mounted to the framework against soft neoprene gaskets by means of bolting (25).

The hood panels consist of 1.2mm steel which are lined on the inside with 50mm thick acoustic lining. (Acoustic liner = 47kg/m³ glass wool boards with glass cloth facing, attached to the panels with contact adhesive and secured with perforated steel face plate.

If a more water resistant finish is required then the same glass wool product can be used, but the Aluminized Mylar facing should be specified, with a maximum thickness of 75µm. The glass cloth facing will yield a decidedly better acoustical absorption performance with the LHD noise spectrum under consideration (25).

The noise screening of the driver's cab was achieved through the installation of 6.5mm laminated (safety) glass on two sides of the driver's cabin, one on the driver's right hand side and the other behind him. The front and left sides were left open, an additional panel in front of the driver would be useful but was deemed impractical due to the LHD controls being located in this area.

The glass panes were mounted in steel frames with soft rubber gaskets. The purpose of the glazing was not to soundproof the cab, but to act as a proximity noise screen for the driver's ear. The roof of the driver's cabin was insulated with acoustic absorption was installed on the inside of the roof. The acoustic material comprised of glass wool board with a glass cloth facing and was secured with perforated plate. The glass wool in this application was 100mm thick. (2 x 50mm boards) (25).

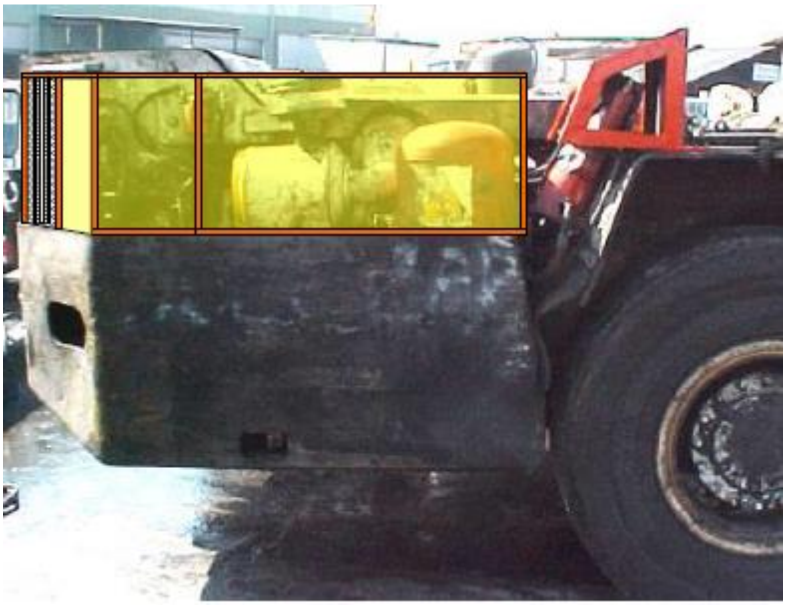


Figure 2: Engine noise hood side view R.H. side opposite driver (25).

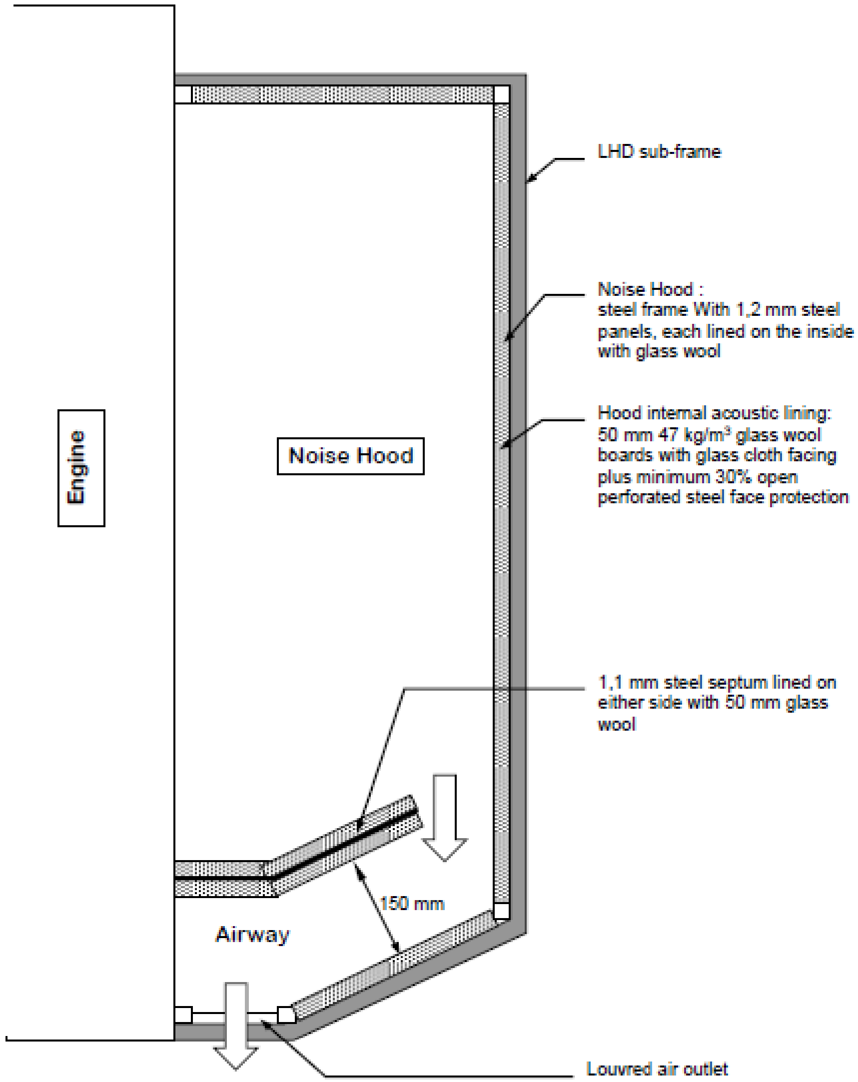


Figure 3: Engine hood concept with natural ventilation (25).

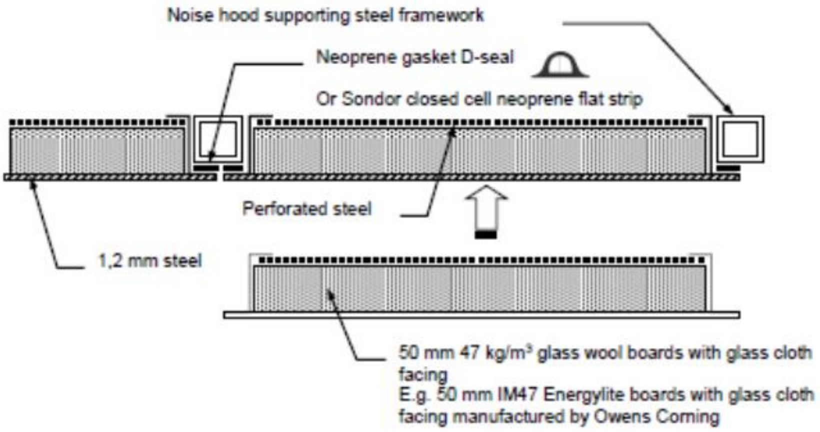


Figure 4: Engine hood panel (Plan View) (25).

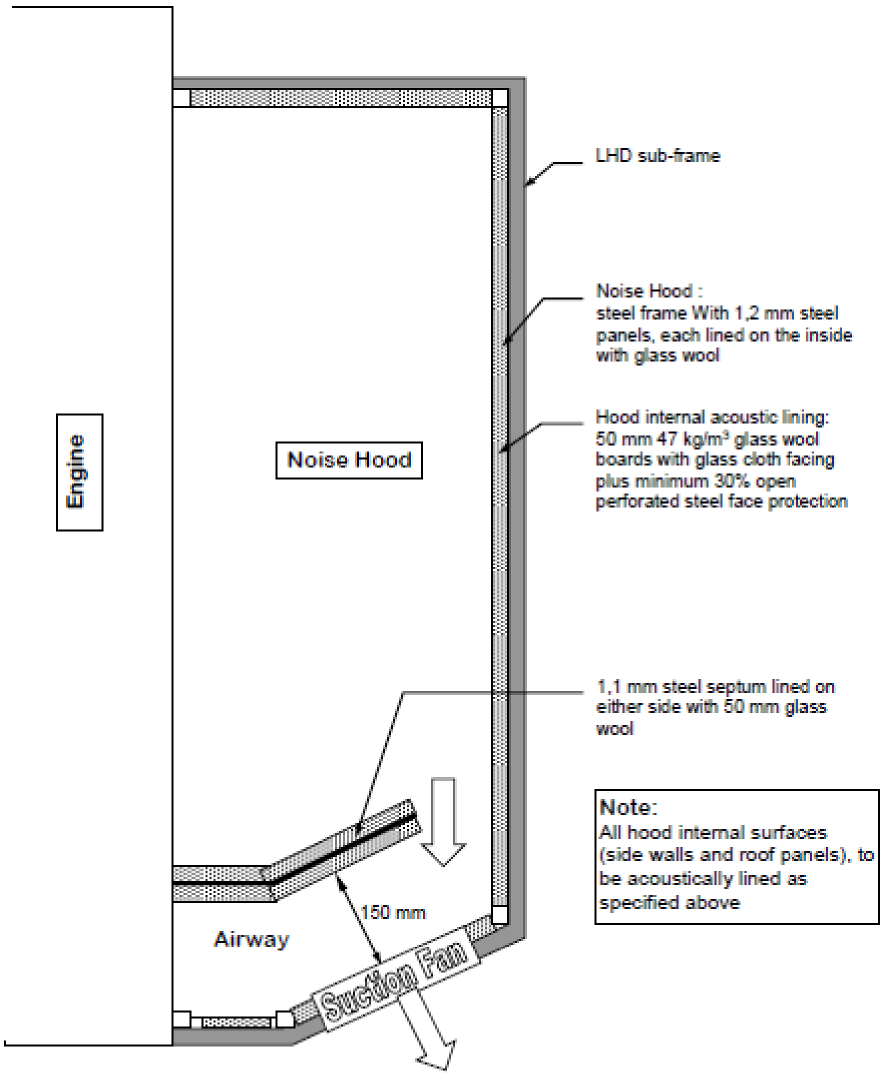


Figure 5: Engine hood concept with fan assisted ventilation (25).

Figure 6: Driver's cab (25).

Conclusion

Noise reduction in the old era load haul dump machines is possible as shown in Figure 7. Though reflection and reverberation levels were added (estimated values) and the machine not having been tested in the underground workings, the surface testing is still a reflection of the noise level reduction that can be achieved.

As no papers were available on the new era load haul dumpers with enclosed engine compartment and closed air-conditioned cab one can only assume that the changes have had a significant reduction of noise exposure to the driver.

It would however be prudent to just accept that the new developments have achieved the required noise reduction. This is therefore an area that requires further testing and should be the responsibility of the OEM, but should be carried out in conjunction with the mining houses making use of such equipment.

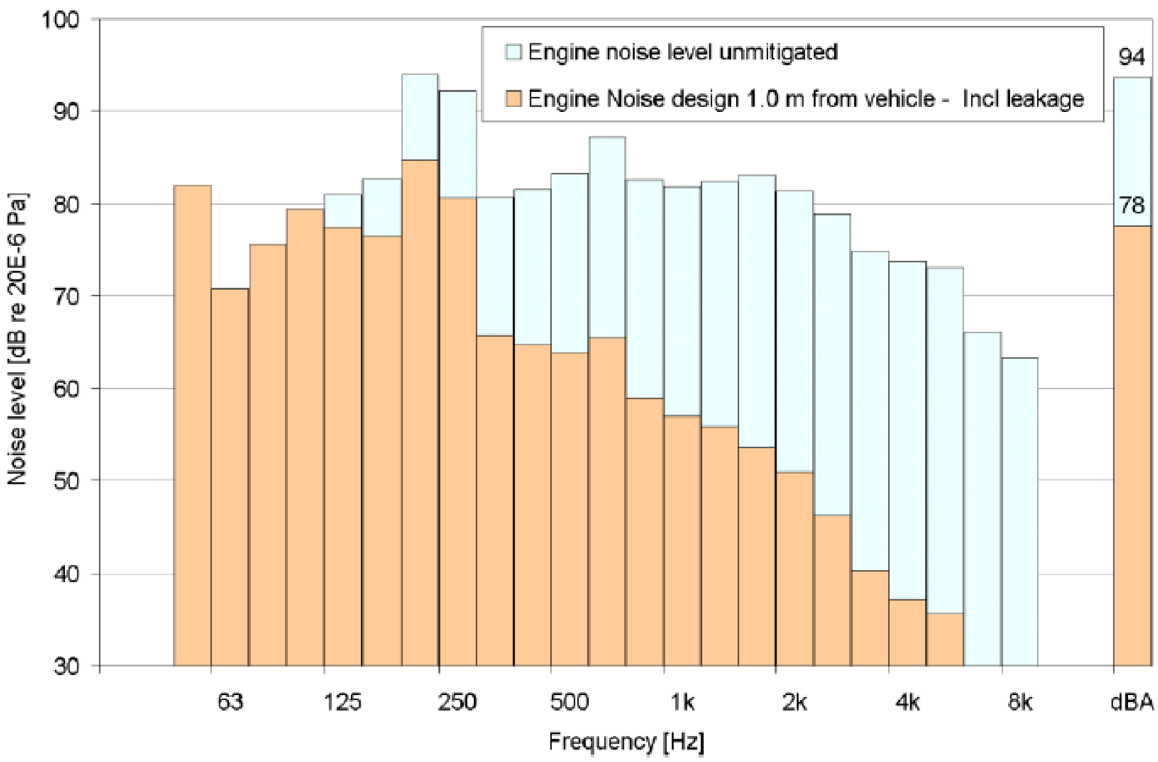


Figure 7: Noise level reduction following the acoustic damping (25).

Engineering noise control (Professor Colin H. Hansen – Department of mechanical engineering – University of Adelaide, Dr. Berenice I.F. Goelzer – W.H.O.) (26).

Summary of paper

The paper outlines the requirements to implement control technology which should aim at reducing noise to an acceptable level. The considerations are not purely engineering related, but refer to a combination of measures which by themselves would be insufficient to meet the requirements targeted. The paper also outlines a number of International Standards Organization (ISO) Standards which are constantly referred to in the paper.

To adequately define the noise problem and set a good basis for the control strategy, the following factors should be considered:

- Type of noise
- Noise levels and temporal pattern
- Frequency distribution
- Noise sources (location, power, directivity)
- Noise propagation pathways, through air or through structure
- Room acoustics (reverberation).
- In addition, other factors have to be considered (26)

Normally the noise control program will be started using as a basis A-weighted emission or noise exposure levels for which the standard ISO 11690-1 recommends target values and the principles of noise control planning. A more precise way is to use emission and emission values in frequency bands as follows:

- The desired (least annoying) octave band frequency spectrum for which to aim at the location of the exposed worker is shown in Figure 10.1 for an overall level of 90 dB(A). If the desired level after control is 85 dB (A), then the entire curve should be displaced downwards by 5dB.

- The curve is used by determining the spectrum levels in octave bands and plotting the results on the graph to determine the required decibel reductions for each octave band. Clearly it will often be difficult to achieve the desired noise spectrum, but at least it provides a goal for which to aim.

- Any noise problem can be described in terms of a source, a transmission path and a receiver (26).

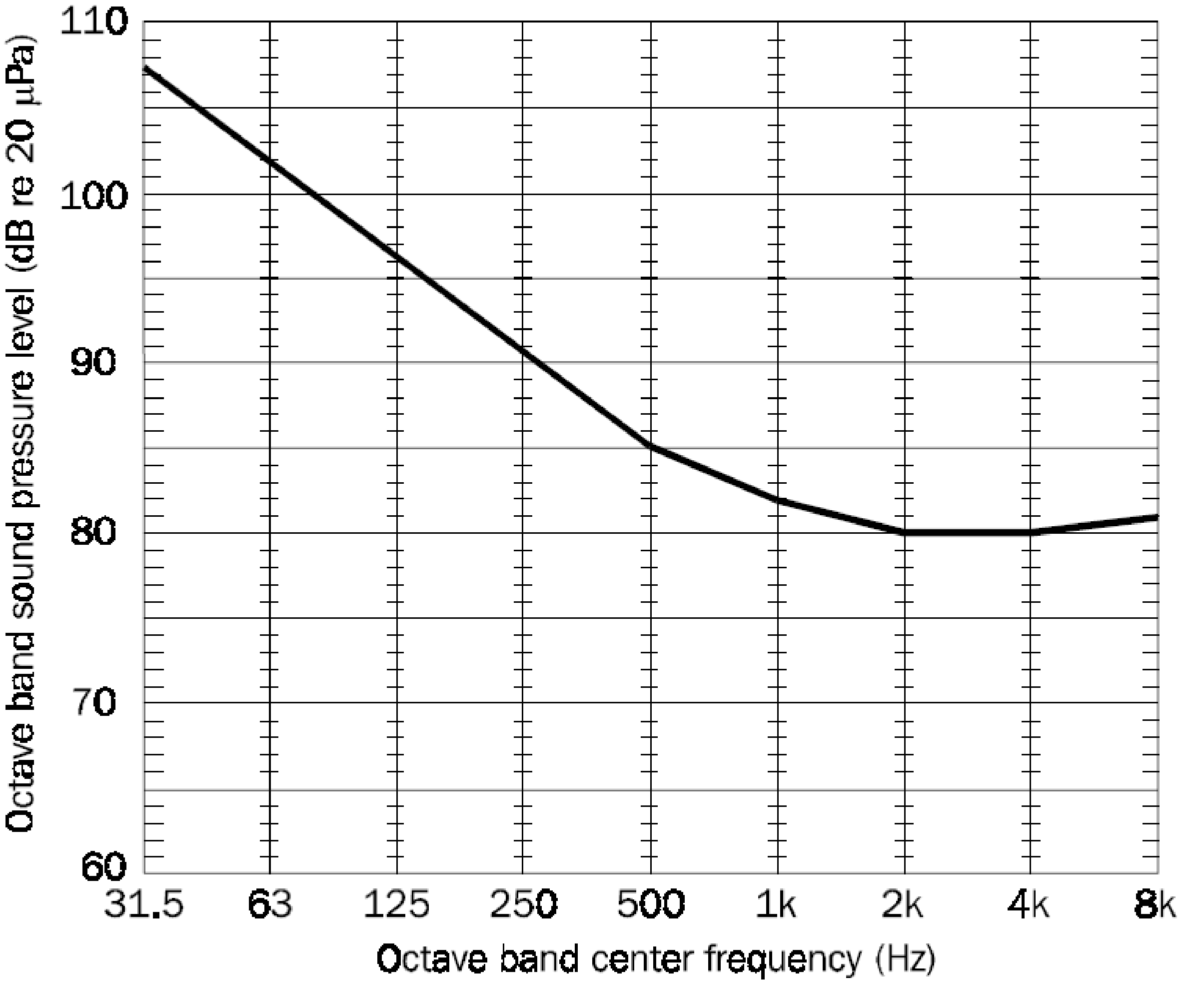


Figure 1 – Desired noise spectrum for an overall level of 90 dB (A) (26).

Discussion

Many people/ companies select their machinery or equipment using only noise emission values according to ISO 4871, they however make their comparison according to ISO 11689. The radiated sound power and directivity of sources can be determined by reference to the equipment manufacturers data, of which is outlined in ISO 4871 (26).

Control of noise at the source

The first step for new installations is to determine the noise criteria for sensitive locations which may typically include locations of operators of noisy machinery. If the estimated noise levels at any sensitive location exceed the established criteria, then the equipment contributing most to the excess levels should be targeted for noise control, which could take the form of:

- Specifying lower equipment noise levels to the equipment manufacturer (care must be taken whenever importing equipment, particularly second hand which can be very noisy and hence no longer acceptable in the country of origin);
- Including noise control fixtures (mufflers, barriers, vibration isolation systems, enclosures, or factory walls with a higher sound transmission loss) in the factory design; or

- Re-arrangement and careful planning of buildings and equipment within them. The essence of the discussion is that sources placed near hard reflective surfaces will result in higher sound levels at the approximate rate of 3 dB for each large surface. Note that the shape of the building space generally is not important, as a reverberant field can build-up in spaces of any shape. Care should be taken to organize production lines so that noisy equipment is separated from workers as much as possible. Sufficient noise control should be specified to leave no doubt that the noise criteria will be met at every sensitive location. Saving money at this stage is not cost effective in the long term (26).

Among the physical phenomena which can give origin to noise, the following can be mentioned:

- Mechanical shock between solids,
- Unbalanced rotating equipment
- Friction between metal parts,
- Vibration of large plates,
- Irregular fluid flow, etc (26).

General noise source control can involve:

- Maintenance
- Substitution of materials
- Substitution of equipment
- Specification of quiet equipment
- Substitution of equipment parts
- Change in work methods
- Substitution of processes
- Substitution of mechanical power generation and transmission equipment
- Replacement of worn moving parts
- Minimizing the number of machines running together at any given point of time (26).

A number of practical examples of addressing noise reduction in various types of equipment are given by means of illustrations. One particular area on which I raised the need to address the noise generated by out of balance equipment (attenuation of rock drill vibration- SIMRAC GAP 634 – JPD Strydom) is described in this paper under “Source control by design”(20)

Reduction of noise resulting from Out-Of-Balance

Here we need to consider the balancing of moving parts, the use of vibration absorbers and dampers (where it is not detrimental to the design of the machine) – Previously discussed under the paper, (Analysis of a mechanism suspension to reduce noise from horizontal vibrating screens (21). (NIOSH – David S Yantek and M. Jenae Lowe – 2011)

Reduction in noise resulting from friction between metal parts

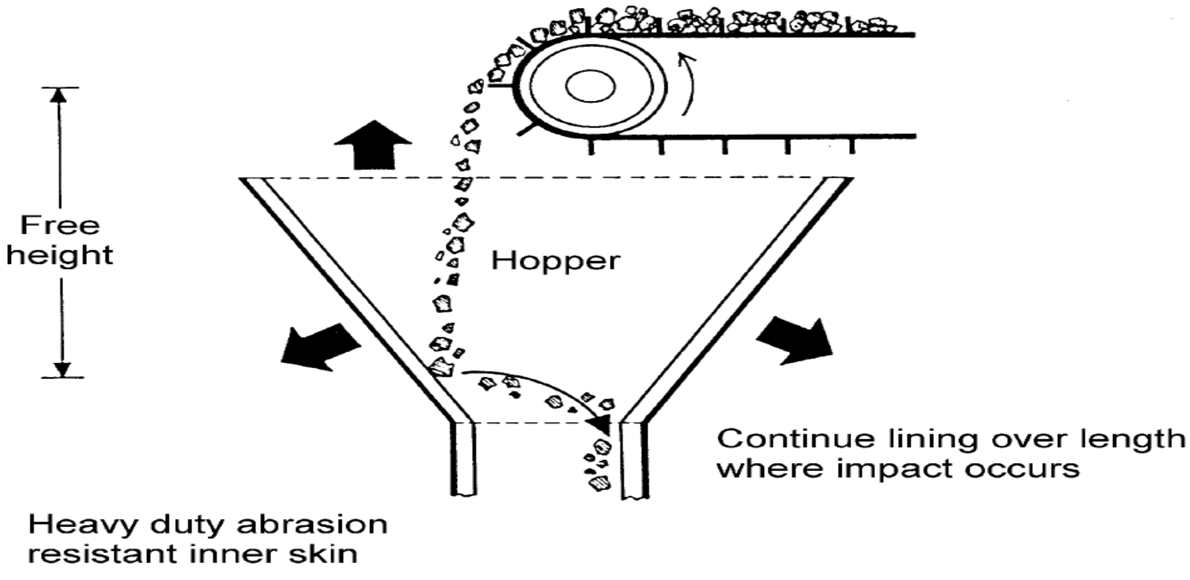
This can be addressed by means of lubrication or use of a soft elastic interspacing (26).

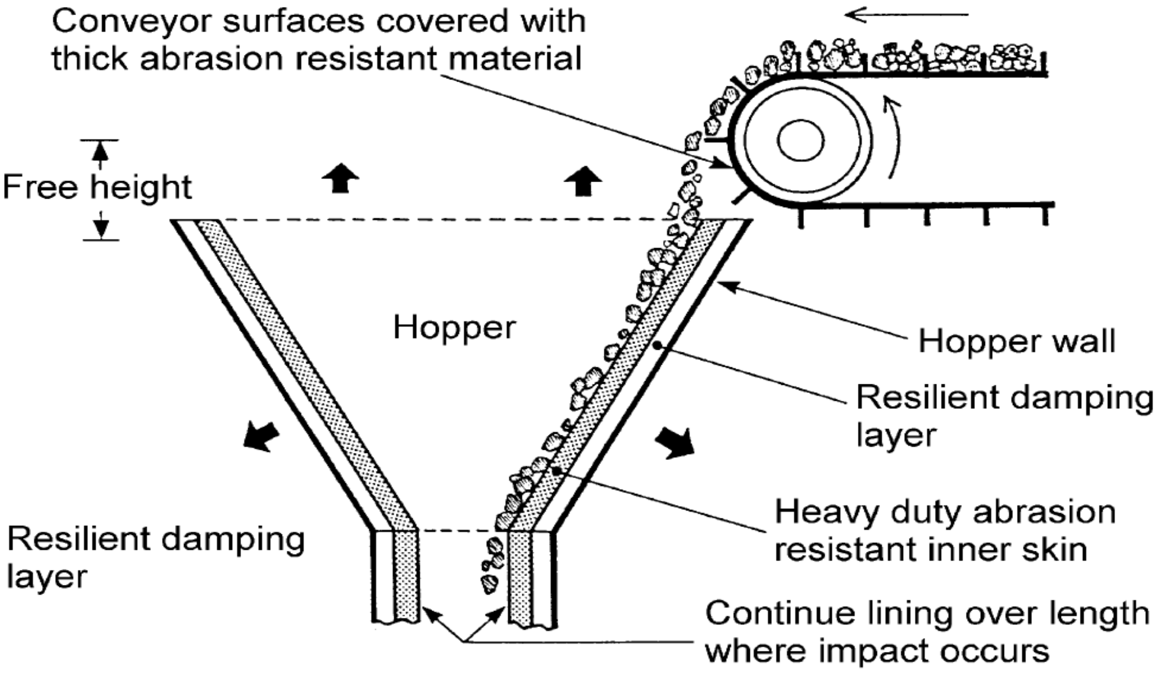
Reduction of noise resulting from vibration of large structures

(Plates, beams and other steel work)

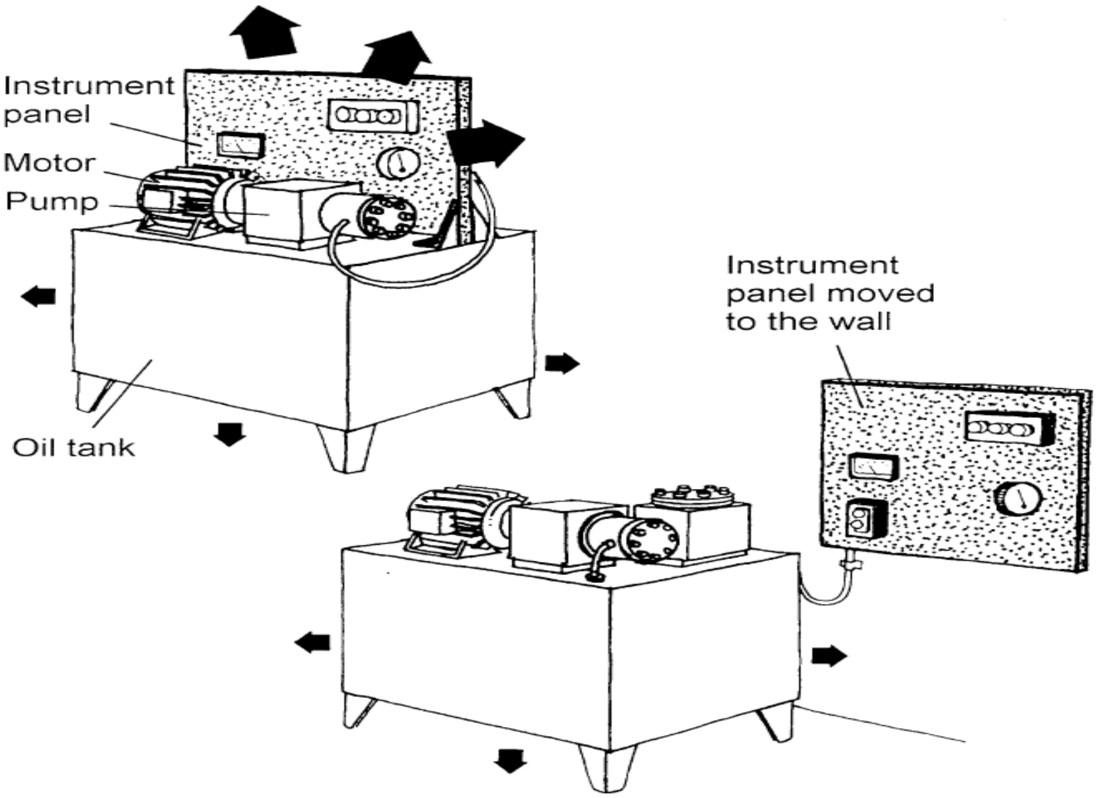
- Ensuring that machine rotational speeds do not coincide with resonance frequencies of the supporting structure, and if they do, changing the stiffness or mass of the supporting structure to change its resonance frequencies (increasing stiffness increases resonance frequencies and increasing the mass reduces resonance frequencies);
- Reducing the acoustic radiation efficiency of the vibrating surface by
  - Replacement of a solid panel or machine guard with a woven mesh or perforated panel
  - Use of narrower belt drives, etc.
- Damping a panel if it is excited mechanically, (but note that if the panel is excited by an acoustic field, damping will have little or no effect upon its sound radiation)
  - The amount of damping already characterizing a structure can be approximately determined by tapping it with a steel tool or rod. If the structure "rings" for a period after it is struck, then the damping is low. If only a dull thud is heard, then the damping is high. If the damping is low, then the surface may be treated either with a single layer damping treatment or a constrained layer treatment as described below. The noise reduction achieved is usually in the range 2 to 10 dB (26).

The two figures below depict a hopper with an impact absorbing and damping construction. (Note that to achieve a constraint layer treatment, the "heavy duty abrasion resistant inner skin" could be replaced with a steel plate (26).

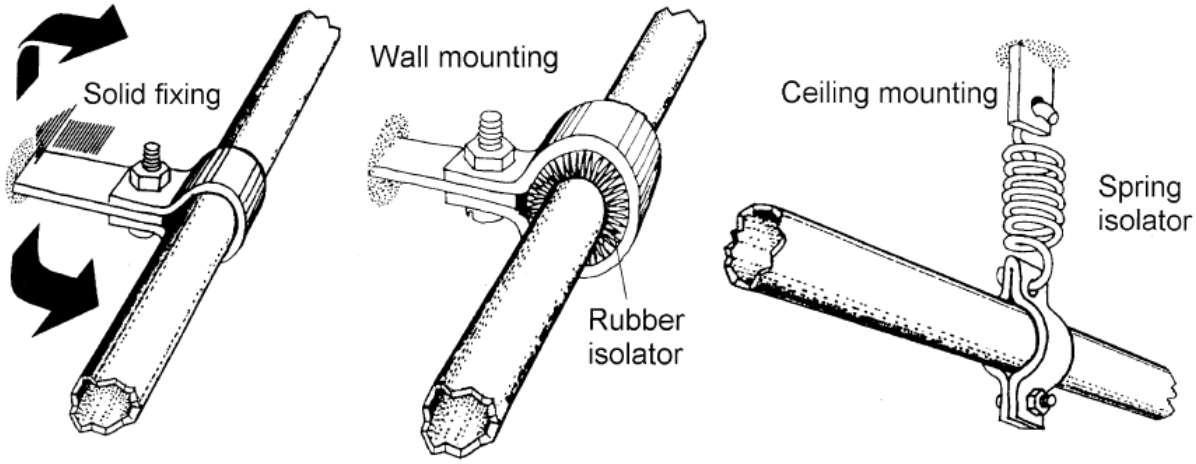




The figure below depicts vibration isolation through separation(26).



The figure below provides practical means in reducing vibration generated noise from piping (26).



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