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Noise of Sheep Shearing Systems
Part 2: Noise Source Identification

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Summary

In part one of this study, the magnitude of the noise levels of four shearing systems were reported. In this, part two of the study, the sources of the noise of the shearing systems are investigated to focus future efforts to reduce the magnitude of the noise of the shearing systems.

Efforts to reduce the magnitude of the noise of the shearing systems should include efforts to reduce the noise generated by the hand piece. The primary source of the noise of the hand piece is the friction noise generated by the motion of the cutter over the comb. Friction noise is dependent on the roughness of the surfaces and the speed of the motion of the cutter.

Additional reductions in the noise levels of the shearing system can be achieved by redesigning the down tube to reduce the unbalance of the down tube core and the contact between the core and the outer tube.

Improvements to the gear sets in the down tube and between the down tube and the hand piece are also expected to reduce the noise of the shearing systems, but not as much as the other recommended changes.

Table of Contents

1. Introduction

This report represents the second part of a study of the noise of sheep shearing systems. In part one of the study, the noise levels of four shearing systems were compared. In this part two of the study, the sources of the noise are investigated to focus future efforts to reduce the noise of shearing systems.

2. Evaluated Shearing Systems

The shearing systems included in the evaluation are listed in Table 1.

Plant	Hand Piece	Comb	Cutter
Heiniger EVO 3 Speed	Heiniger ICON	Heiniger Charger	Heiniger Edge
Lister Nexus	Lister Mamba	Lister Buzzard	Lister Claw
Shear Grunt Eliminator	Lister Mamba	Lister Buzzard	Lister Claw
Supershear	Supershear Viper	Supershear Mustang	Supershear Quattro

Table 1: Shearing systems included in the evaluation.

New equipment was requested for the evaluation since used equipment could have been subjected to widely varying usage and environmental conditions which could affect the noise levels of the equipment.

In the interest of confidentiality, the shearing systems are referred to in the study as systems A, B, C and D. The assignment of the letters was random and did not correlate to the list in Table 1. Furthermore, the figures presented in this report are shown without any indication of the frequency on the axes. The omission was intentionally done to make it difficult to identify the shearing systems based on the figures.

3. Measurements

All of the data presented in this report was measured in the 217 m^3 reverberation room at the University of Canterbury. The walls of the room are concrete and the total surface area is 270.5 m^2. Diffusers are located throughout the room. The source and microphones were located in the reverberation room in accordance with ISO 3741:1999. The microphones were located at least 1 m from any reflective surface, 1.7 m from other microphone positions and 1.2 m from the source. The equipment used for the measurements is detailed in Appendix A.

The results presented in part one of this study showed that the measured sound power levels of all of the shearing systems were highest when the hand piece was held in position 1 as shown in Figure 1.

Figure 1: Hand piece held at position 1.

When held in position 1, the hand piece was located at a height of 0.5 m from the ground and the down tube was at a 15 degree angle relative to the wall onto which the plant was mounted. Since the highest noise levels were measured while the hand piece was held at position 1, data measured for this position was used to evaluate the sources of the noise.

The sound pressure level of the shearing systems was measured while the equipment was run under the no load condition. The measurements were made under the supervision of Barry Pullin. Oil was applied to the comb and cutter every twenty seconds. The duration of the testing was 45 seconds.

The data which was collected included both 1/3 octave band and the narrow band data. The maximum sound pressure level measured at each frequency at ten microphone positions in the reverberation room was used for the evaluation of the narrow band data to ensure that all of the peaks in the frequency range were included in the evaluation.

3.1. Additional Measurements

In order to quantify the contribution of the noise from the hand piece to the noise of the complete shearing system, the sound pressure level was measured when the hand piece was disconnected from the down tube. During the measurements without the hand piece, the down tube was held in the same position as it was when the hand piece was connected to the down tube and held in position 1. The sound pressure level of the complete shearing system was also measured again to be used as a comparison against the sound pressure level measured without the hand piece.

These additional measurements were made at a later date than the original measurements and without the assistance of Barry Pullin, but following his original directions. The magnitude of the additional measurements can not be reported as being made according to a standard and any data from these measurements is noted as being so in this report to separate it from the original data collected under the supervision of Barry Pullin.

3.2. Narrow Band Data

The data presented in this report shows the magnitude of the measured sound pressure level at discrete frequencies. Data reported at discrete frequencies is commonly referred to as narrow band data as opposed to the data shown in the much wider 1/3 octave bands as presented in part one of this study. Whereas 1/3 octave band data is useful to quickly compare the noise levels of the different shearing systems, narrow band data is useful for determining the sources of the noise [1, 2]. For example, gear tooth wear can cause a peak in the narrow band data at the gear natural frequency which is the number of teeth times the speed of rotation of the gear in Hz. Mechanical looseness in the shaft can lead to peaks at multiples of the rotational speed of the shaft plus fractions of the rotational speed of the shaft.

The narrow band data can be correlated to data presented in 1/3 octave bands. Esentially, 1/3 octave band data can be calculated by summing up the narrow band data within a designated frequency band. The width of the frequency band depends on the frequency of the 1/3 octave band centre frequency as shown in Table 2.

Frequency (Hz)			
Center	Lower	Upper	Span
100	89.09	112.25	23.16
125	111.36	140.31	28.95
160	142.54	179.59	37.05
3150	2806.33	3535.76	729.42
4000	3563.59	4489.85	926.25
5000	4454.49	5612.31	1157.82

Table 2: Centre, lower and upper limits of the 1/3 octave band centre frequencies.

The table shows that the 1/3 octave bands at the higher frequencies include more narrow band data than those at the lower frequencies. Therefore, a noise source with a flat response across the narrow band spectrum will have a higher magnitude in the 5000 Hz 1/3 octave band than at the 100 Hz 1/3 octave band due to the inclusion of more data in the 5000 Hz 1/3 octave band.

4. Measurement Results

The sound pressure levels of the shearing systems measured in the frequency range from 10 Hz to 12800 Hz are shown in the following figures.

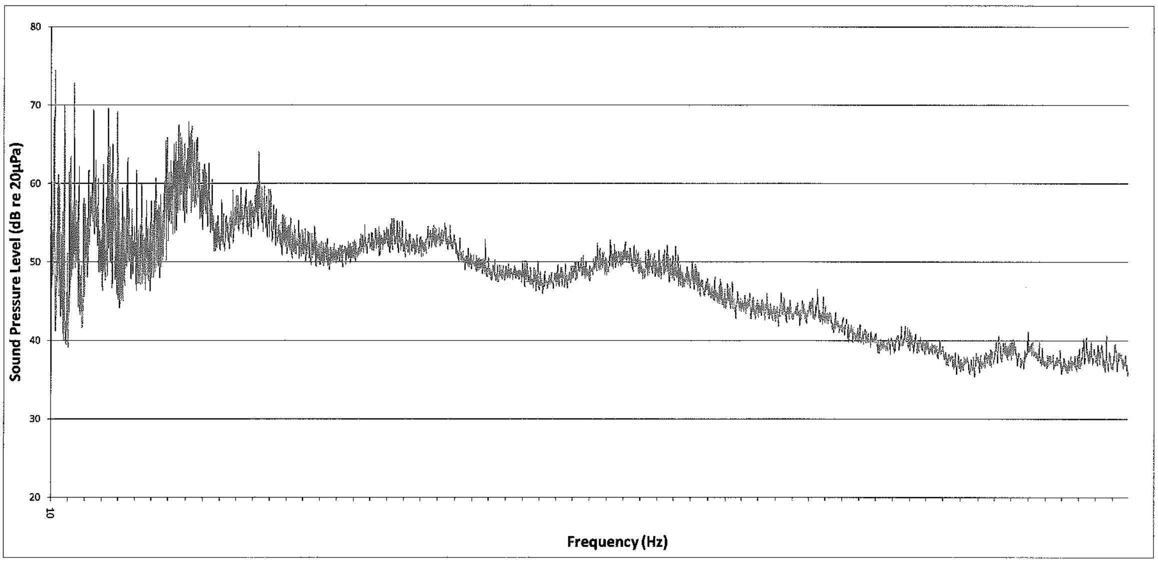

Figure 2: Measured sound pressure level of shearing system A.

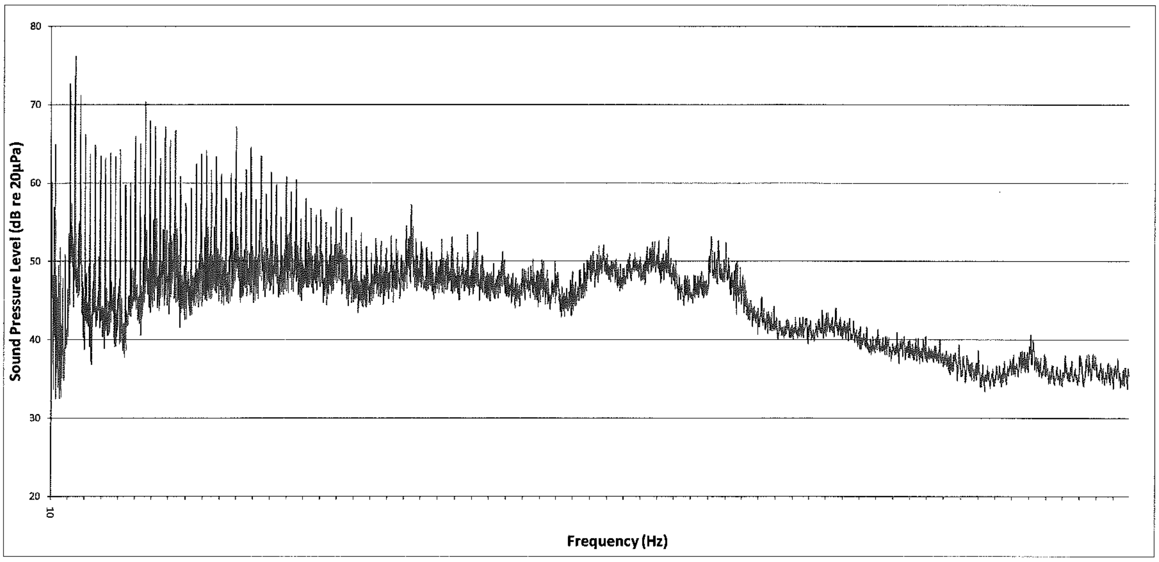

Figure 3: Measured sound pressure level of shearing system B.

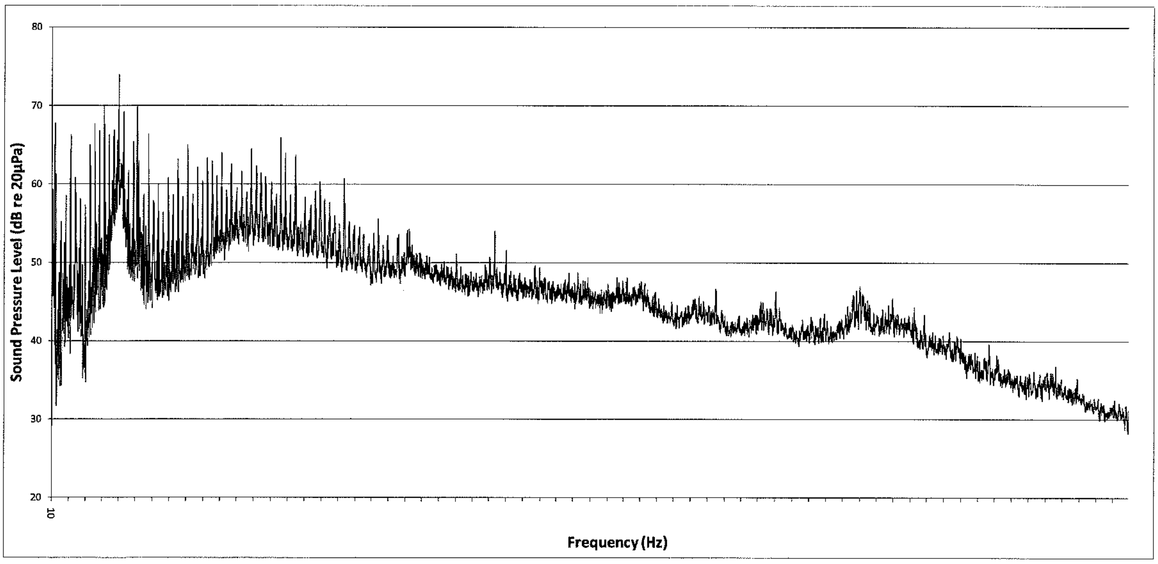

Figure 4: Measured sound pressure level of shearing system C.

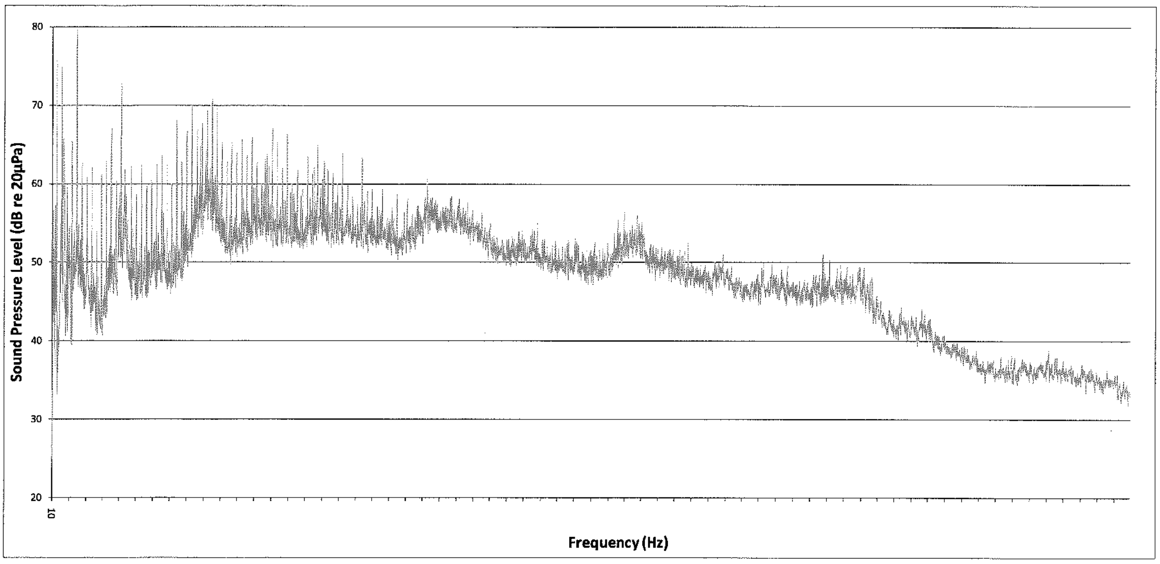

Figure 5: Measured sound pressure level of shearing system D.

The narrow band sound pressure levels shown in the figures each have peaks of different magnitudes and frequencies. However, overall the sound pressure levels of the different shearing systems show similar trends with respect to frequency as can be seen in Figure 6.

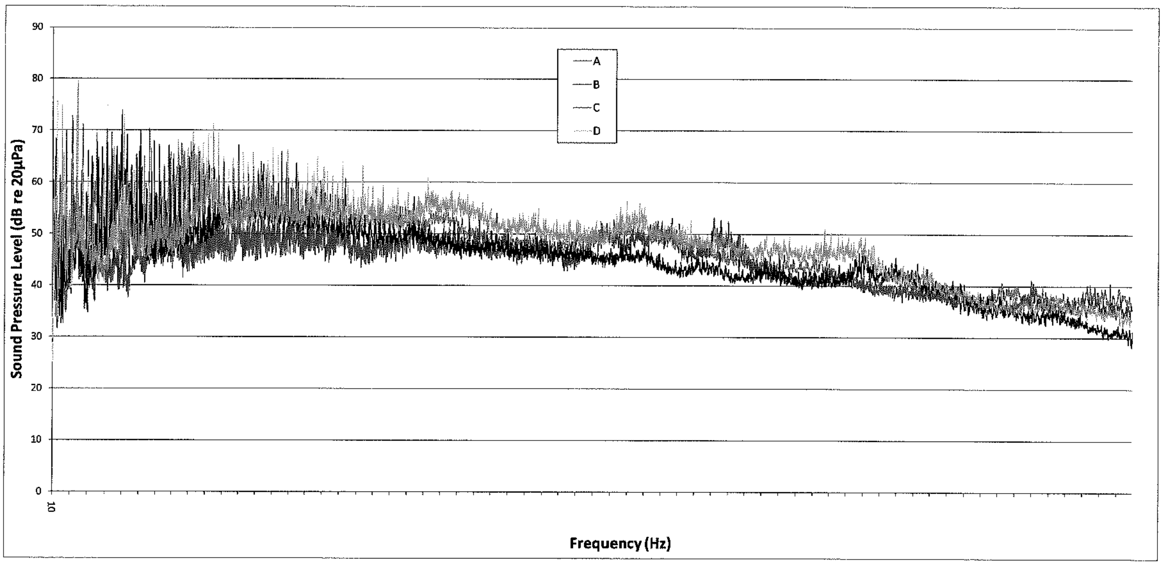

Figure 6: Comparison between the sound pressure levels of all of the shearing systems from 10 Hz to 12800 Hz.

The sound pressure levels of the shearing systems are shown in the above figure to increase in magnitude up to approximately 1600 Hz, then plateau up to approximately 4000 Hz and then steadily decrease with increasing frequency.

In part one of this study, it was shown that the magnitude of the sound power levels of the shearing systems were highest above the 1600 Hz 1/3 octave band even thought the sound pressure levels shown in Figure 6 decrease with increasing frequency above 4000 Hz. The higher magnitude sound power levels in the bands above the 1600 Hz 1/3 octave band were due to the wider frequency bands at the higher frequencies than at the lower frequencies. Therefore, although the peaks in the sound pressure levels at the lower frequencies represent the highest sound pressure levels which were measured for each of the shearing systems, the most efficient reduction of the total sound power levels of the shearing machines may be achieved by further reducing the sound pressure levels at the frequencies above approximately 1600 Hz.

5. Evaluation of the Noise Sources

5.1. Evaluation of Narrow Band Data

The narrow band sound pressure levels of each shearing system as measured under the supervision of Barry Pullin were evaluated as shown in the following figures. The narrow band data in the figures is shown from 10 Hz to 2000 Hz so that the peaks in the data can be easily observed and identified.

The evaluation of shearing system B is shown in Figure 7.

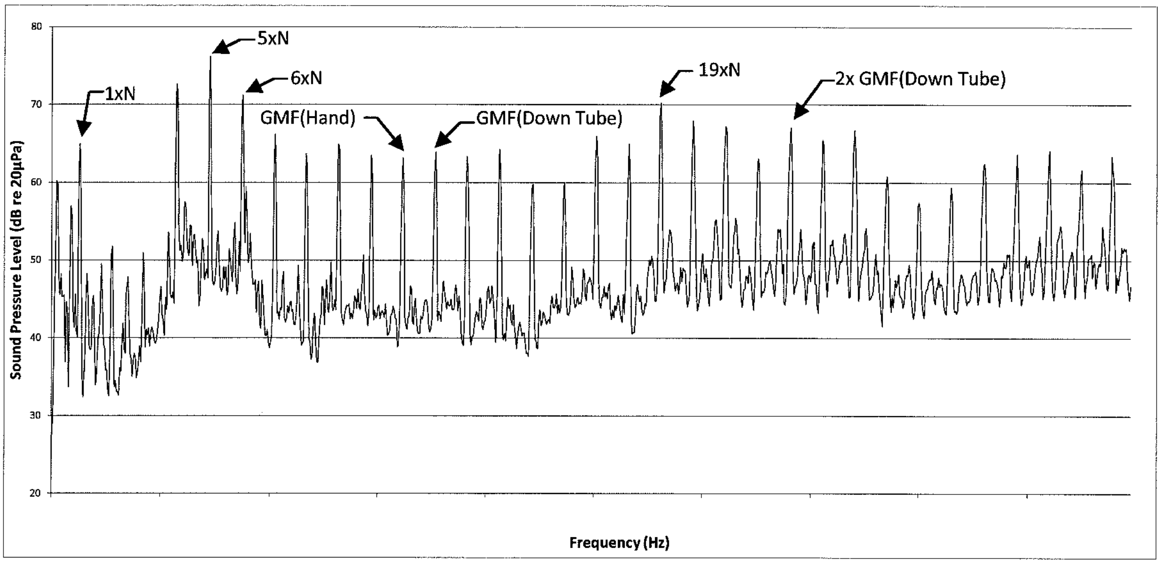

Figure 7: Narrow band data of shearing system B with several peaks identified. N indicates the speed of rotation in Hz and GMF stands for the gear mesh frequency.

The figure shows peaks at multiples of the speed of the down tube shaft rotation throughout the frequency range. The large peak at 5X as well as the peaks at 1/3X, 2/3X and 3/4X suggest that the shaft in the down tube is rubbing the outer tube of the down tube. The peaks at multiples greater than 5X the speed of rotation suggest improper fit between component parts which causes many harmonics due to non-linear response of loose parts to dynamic forces from the shaft. The cause can be a loose shaft or excessive clearance in the ball bearings. The bearings in the down tube may also be cocked and the shaft may be unbalanced.

The figure also shows peaks at the gear mesh frequencies of the hand piece and down tube gears. The peaks at the gear mesh frequencies could indicate damaged gears, but the prominent peaks at multiples of the speed of rotation could also be responsible for the peaks. However, the peak at 2X GMF (Down Tube) shows side bands (smaller peaks on either side of 2X GMF) which suggests shaft misalignment in the down tube gears.

The narrow band spectrum of shearing system C is shown in Figure 8.

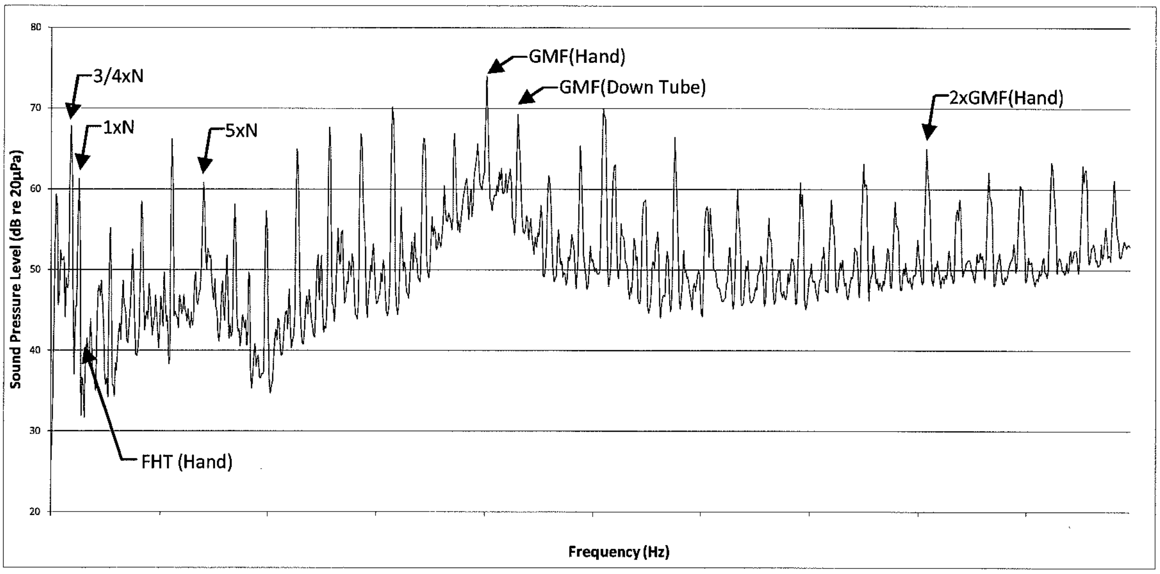

Figure 8: Narrow band data of shearing system C with several peaks identified. N indicates the speed of rotation in Hz, FHT stands for the hunting tooth frequency and GMF stands for the gear mesh frequency.

Shearing system C also shows signs of unbalance, shaft rub, loose parts and improper fit between components in the down tube. The largest and widest peak in the spectrum is shown to be at the gear mesh frequency of the hand piece which suggests damage to the gear as well as gear eccentricity or backlash. Furthermore, the peak at the hunting tooth frequency of the hand piece gear indicates that there may be a fault with the gear set that occurred during manufacturing or due to mishandling [3].

The peak at GMF(Hand) shown in Figure 8 corresponds to the peak which was seen in the 1/3 octave band spectrum of shearing system C as shown in Figure 9.

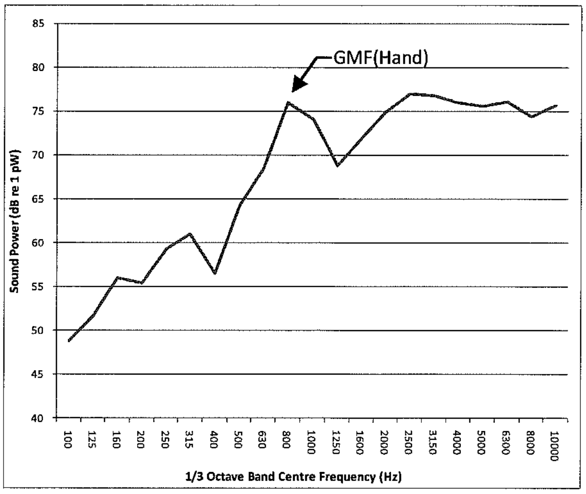

Figure 9: Sound power level of shearing system C in 1/3 octave bands as reported in part one of the study.

Therefore, the problems with the hand piece gear set of shearing system C contributed to the total sound power level reported in part one of this study. If the peak could be reduced as shown in Figure 10 by fixing the problem with the gear set, the sound power level of shearing system C could potentially be reduced from 86.1 dB to 85.5 dB.

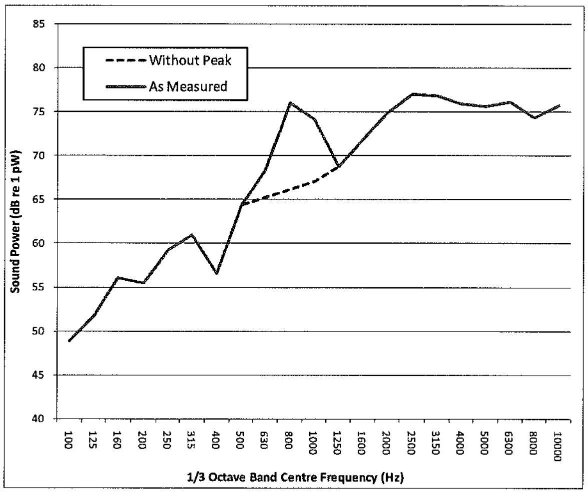

Figure 10: Sound power level of shearing system C in 1/3 octave bands as reported in part one of the study and without the contribution of the peak at the gear mesh frequency.

The narrow band spectrum of shearing system D is shown in Figure 11.

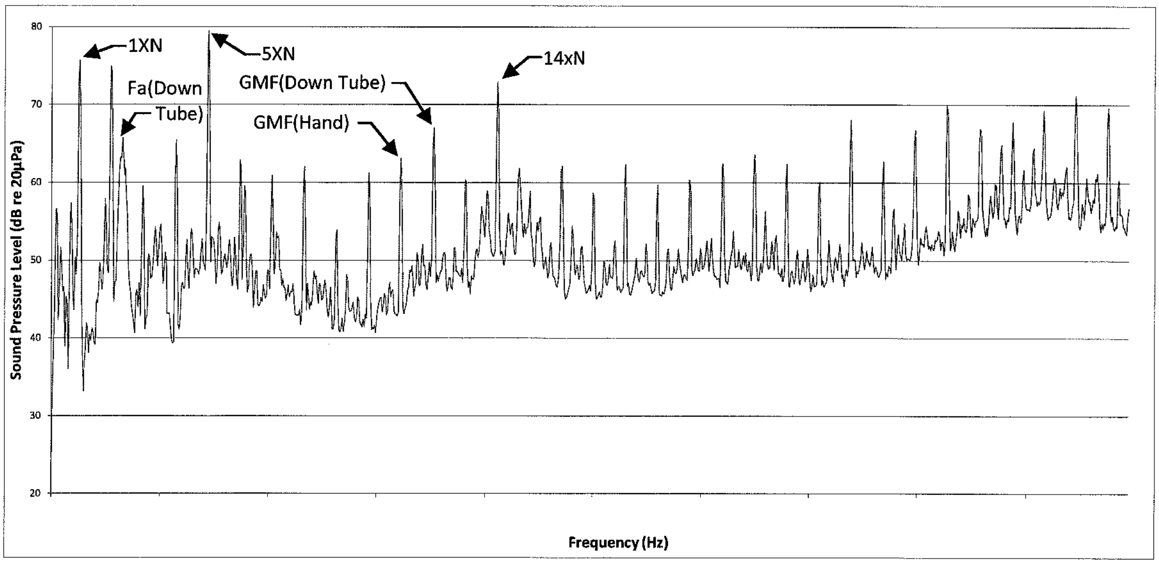

Figure 11: Narrow band data of shearing system D. N indicates the speed of rotation in Hz, Fa stands for the assembly phase frequency and GMF stands for the gear mesh frequency.

As with the other shearing systems, the narrow band data suggests shaft rub, loose parts and improper fit between components in the down tube. There is also a wide peak at approximately the assembly phase frequency of the down tube gear set which indicates possible manufacturing problems or damage to the gears from contamination. The peak at the assembly phase frequency corresponds to a peak in the sound power level in the 125 Hz 1/3 octave band for shearing system D as reported in part one of this study.

The narrow band spectrum of shearing system A is shown in Figure 12 from 10 to 2000 Hz.

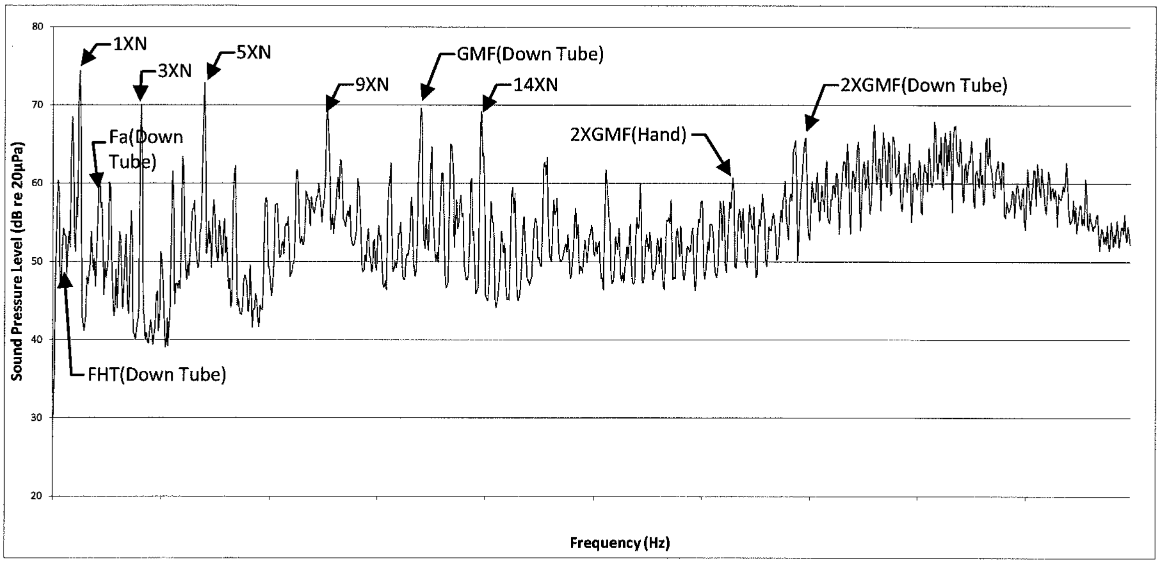

Figure 12: Narrow band data of shearing system A from 10 to 2000 Hz with several peaks identified. N indicates the speed of rotation in Hz, Fa stands for the assembly phase frequency, FHT stands for the hunting tooth frequency and GMF stands for the gear mesh frequency.

Although the narrow band data shown in the figure lacks the prominent peaks across the spectrum at multiples of the speed of rotation which occurred in the spectrums of the other shearing systems, there is still evidence of noise originating from the down tube. The figure shows peaks as high as 14X the speed of rotation, suggesting shaft rub, loose parts and improper fit between components in the down tube. The peaks at the assembly phase frequency, the hunting tooth frequency and 2X the gear mesh frequency of the down tube gear set suggest that the gear set was damaged.

5.2. Noise from the Hand Piece

The narrow band data measured with and without the hand piece attached to the down tube is shown from 10 Hz to 12800 Hz in Figure 13. These measurements were conducted at a later date than the original measurements and without the supervision of Barry Pullin.

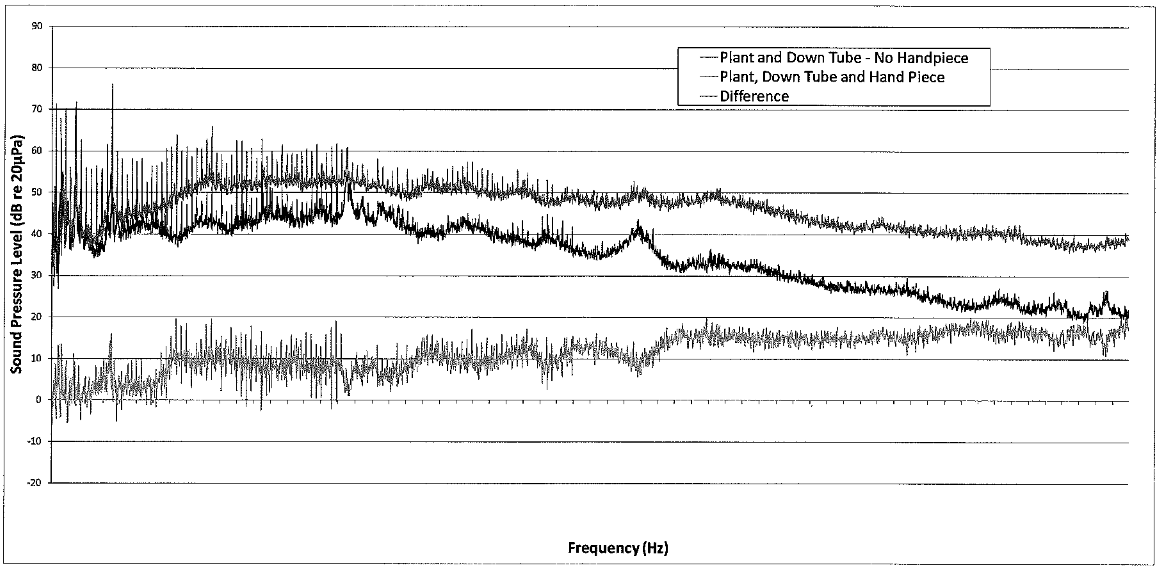

Figure 13: Comparison between the sound pressure level measured for the complete shearing system, the shearing system without the hand piece and the difference between the sound pressure levels.

The figure also shows the difference between the measurements where Difference = $SPL_{complete}$ - $SPL_{no\ handpiece}$.

The figure shows that up to approximately 1200 Hz, the difference between the measured sound pressure levels was on average 3 dB. The 3 dB difference indicates that the noise of the hand piece was twice as loud as the noise of the rest of the components of the shearing system. Between 1200 Hz and 1600 Hz, the magnitude of the difference between the measurements increased by approximately 8 dB. Between approximately 1600 Hz and 7200 Hz, the difference between the measurements was approximately 10 dB.

Above 7200 Hz, the difference between the measurements was approximately 16 dB which indicates that the noise of the hand piece was over five times as loud as the noise of the rest of the shearing system components. The sound pressure level above 7200 Hz lacks the dominant peaks at multiples of the speed of rotation as were found at the lower frequencies. Part one of this study showed that reductions in the sound pressure level above 7200 Hz would have a greater effect than reduction in sound pressure level at lower frequencies. Therefore, efforts to reduce the noise of the shearing system must include reductions in the noise of the hand piece.

Potential sources of noise from the hand piece include the shaft, the internal mechanism which changes the rotational motion of the shaft into the translational motion of the cutter, and the friction noise generated by the motion of the cutter over the comb. Prior studies have shown that friction noise can extend over a wide frequency range and up to frequencies well above 20,000 Hz [4]. Friction noise can be generated by mechanical instabilities when pressure between the sliding surfaces is high or by roughness noise if there is low pressure between the surfaces. Roughness noise is attributed to the numerous impacts between high points on the surfaces as they deform elastically and then return back to their stable positions. The jumps among the positions of the projections generate vibrations in the two sliding surfaces as well as producing responses at the natural frequencies of the components [5]. It has been found that the sound pressure level of the noise caused by the roughness is proportionally to the surface roughness and the sliding speed regardless of the material and the contact geometry [4].

6. Discussion

Unbalance, mechanical looseness and rub in the down tube result in high amplitude sound pressure levels at discrete frequencies which are multiples of the speed of rotation. Improvements in the design of the down tube to prevent the core from rubbing against the sides of the down tube and to reduce the unbalance of the care could decrease the magnitude of the peaks which occurred at multiples of the speed of rotation of the down tube shaft. A reduction in the number and magnitude of these peaks could reduce the sound power level of the shearing systems in the 1/3 octave bands between 1600 Hz and 6300 Hz. It was suggested in part one of this study that reductions in the sound power levels in these 1/3 octave bands would have a larger effect than improvements at the lower frequencies.

To quantify the possible decrease in the total sound power level by redesigning the down tube, the peaks in the narrow band data of shearing system B were smoothed out and the total sound power level was calculated. In this idealized case, a decrease in the total sound power level of 4 dB was achievable by reducing the shaft rub and unbalance in the down tube. Although in practice it may not be possible to remove all of the peaks in the narrow band data through improvements to the down tube design, the potential reduction in the total sound power level show that efforts to reduce the noise of the shearing systems should include efforts to reduce the noise generated by the down tube.

The quality of the bevel gears used in the elbow of the down tube and between the down tube and the hand piece is not known. However, since the gears are exposed to contamination in the shearing shed and since the use of high precision gears is not critical for the application, it is possible that gear sets of low machining tolerances were used. Backlash, the tolerance of the gears and how they are handled during assembly all contribute to the noise of the gears. The investigation of the narrow band data showed that in particular, the gear set between the down tube and the hand piece of all of the systems tested showed signs of either being damaged or of being low quality gears or both. For example, shearing system C showed damage to the hand piece gear set which potentially increased the sound power level of the shearing system by 0.6 dB. Damaged gears can also lead to a premature failure of the bearings. Noise from damaged gears can also cause a low frequency "growl" as perceived by the listener.

Decreases in the total sound power level of the shearing system could also be expected to be achieved by addressing the noise generated from the hand piece. Specifically, reductions in the noise due to the cutter sliding across the comb may have the largest effect on the noise level of the shearing system since the noise which is generated affected the 1600 Hz 1/3 octave band and above. Improvements in the design of the mechanism for converting the rotational motion of the shaft into the translational motion of the cutter may also decrease the noise from the hand piece.

7. Conclusions

Efforts to decrease the noise generated by shearing systems must include efforts to reduce the friction noise of the hand piece. Modifications to the design of the down tube to reduce the unbalance of the core, the rub between the core and the outer tube and mechanical looseness of the down tube components are also expected to decrease the noise of the shearing system. Improvements to the gear sets in the down tube and between the down tube and the hand piece may also reduce the noise of the shearing systems, but not as much as the other recommended changes.

Appendix A: Measurement Equipment

Description	Manufacturer	Model	Serial Number
Analyzer	Brüel & Kjær	PULSE C Frame with 7539 5 Chanel Module	2483932
Acoustic Calibrator	Brüel & Kjær	4231	1934296
Dodecahedron Loudspeaker	Brüel & Kjær	OmniPower 4296	2071500
Dodecahedron Amplifier	Brüel & Kjær	2716	2301358
Barometer	Brüel & Kjær	UZ0001	
Temperature and Humidity Gauge	Kanomax	Cimomaster A531	615588
Microphones	Brüel & Kjær	4189-L	2573559
			2573560
			2573561
			2573562
			2573563

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