TG008: Managing Ultrasonic Emissions

1. INTRODUCTION

The Lee Company's piezoelectric disc pump is a multi-award-winning technology which makes use of advances in the field of non-linear acoustics to offer the following unique features:

- silent operation
- ultra-smooth flow
- millisecond responsiveness
- compact form factor
- high-precision controllability

In contrast to conventional air pumping mechanisms (such as diaphragm and piston pumps), disc pump does not rely on the bulk compression of air within a cavity. Instead, it uses an ultrasonic standing wave, generated within a specially designed acoustic cavity, to create pumped flow. They therefore emit some ultrasound in operation.

This technical guide is intended to provide an introduction to the topic of ultrasound emissions. It provides a review of relevant guidance, typical emission data for disc pumps, and advice on mitigating ultrasound emissions from products.

Figure 1: A piezoelectric disc pump

2. DISCLAIMER

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3. Typical Pump Acoustic Emissions

Typical acoustic emission spectra for an XP Series pump operating at 1W are shown below. These data are the sound pressure level measured at a distance of 30cm from the pump, without any intermediate casework.

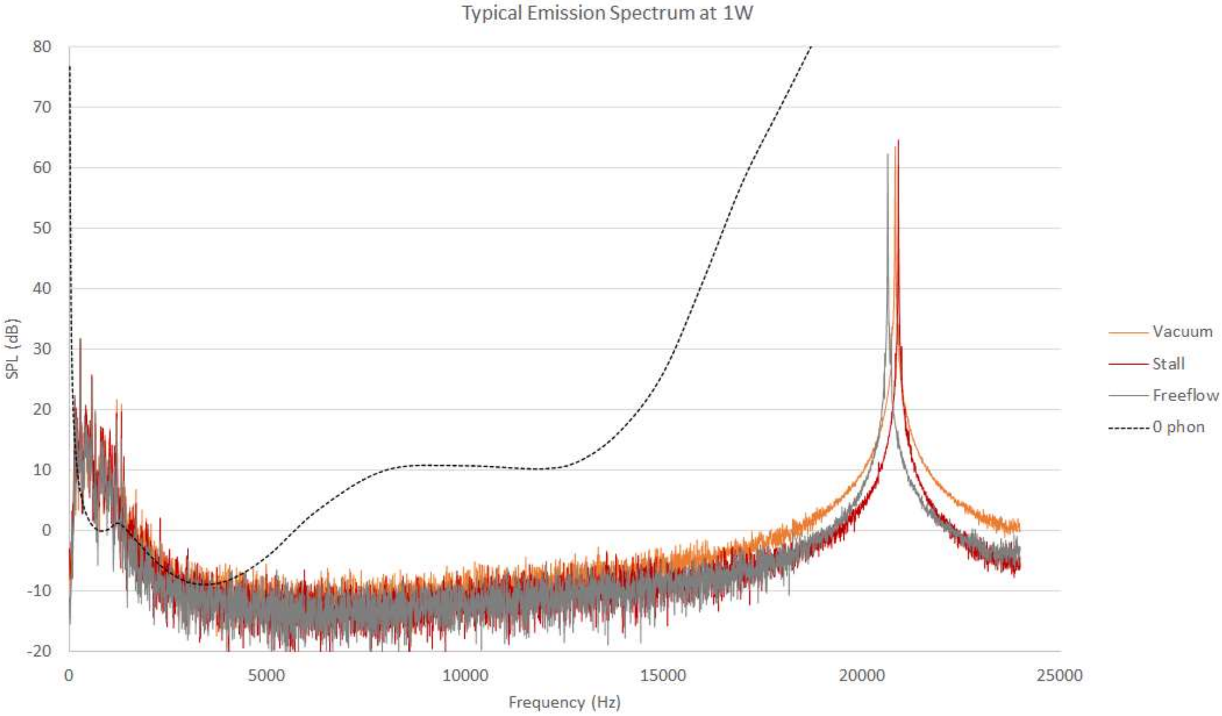

Figure 2. Typical sound emission spectra for XP Series pump operating at 1W, under stall, free-flow, and vacuum stall conditions.

The main peak in each spectrum is at the drive frequency of the pump, typically around 21 kHz. The maximum sound emission at this frequency is between 60 and 65 dB SPL at 30cm, depending on the load condition of the pump.

The dashed line shown on the graph marks the 0 phon level determined according to ISO226:2003 and related studies (see Appendix A for further details). This curve is weighted from the pure dB SPL measurements in order to represent equal loudness as perceived by humans. The line shown, 0 phon, represents the accepted threshold of human hearing as a function of frequency.

It can be seen from the data that the maximum emissions fall well below the 0 phon line except at the very lowest frequencies. Here the experimental data are dominated by background environmental noise. These data are consistent with the observation that the pumps are silent in operation.

4. Ultrasound Emission Limits

4.1. The 20kHz 1/3-Octave Band

A number of reports exist which discuss human response to ultrasound and make recommendations regarding safe occupational exposure levels. These generally divide the frequency spectrum into 1/3-octave bands for simplicity. Relevant bands are:

1/3 Octave Band	Lower frequency	Upper frequency
16 kHz Band	14.1	17.8
20 kHz Band	17.8	22.4
25 kHz Band	22.4	28.2

It should be noted that the 20kHz band spans a frequency range in which the sensitivity of the human ear changes dramatically, reducing by 25 dB between 18 kHz and 20kHz alone.[1] This is illustrated in Figure 2, which shows the very rapid increase in the human hearing threshold above 15kHz.

Disc Pumps operate exclusively in the upper half of the 20 kHz band. Therefore, even at their lowest operating frequency, their sound emissions are 25 dB less audible than an 18kHz source (part of the same notional band).

[1] See Appendix A.

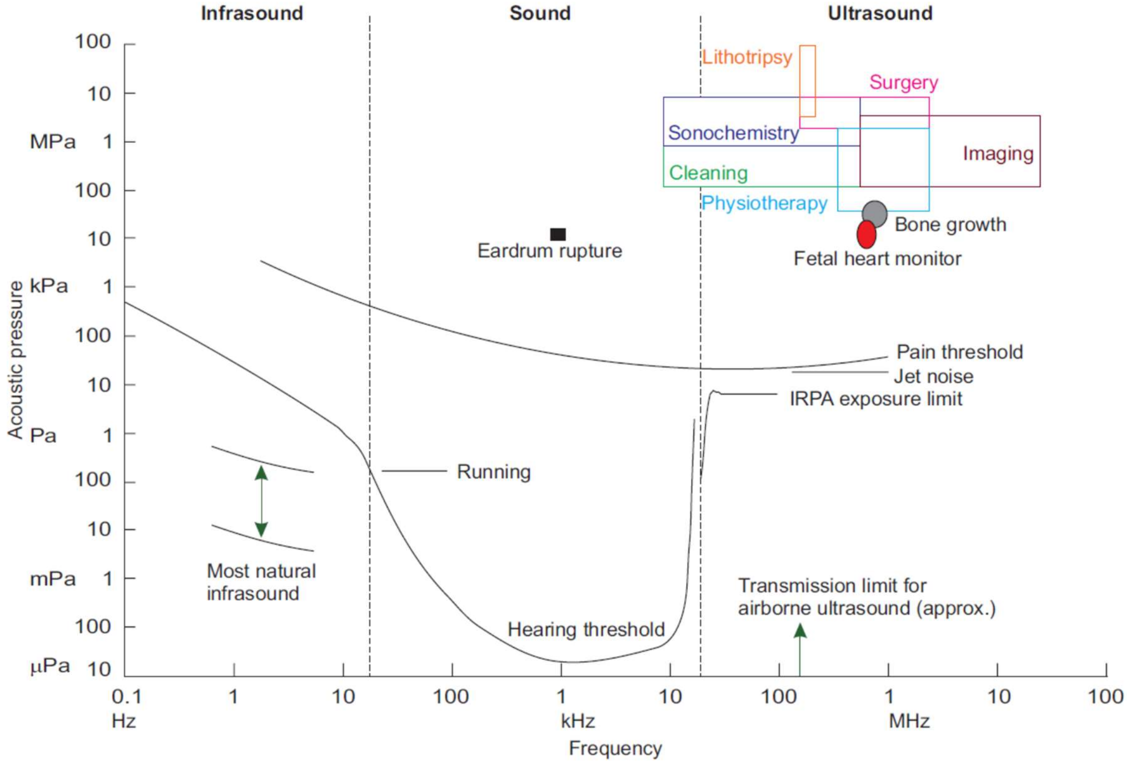

Figure 2 Hearing threshold and physiological effects as a function of sound frequency.[2] Typical Disc Pump emission of 65 dB SPL equates to a sound pressure of 36 mPa.

[2] Public Health England RCE-14: Health Effects of Exposure to Ultrasound and Infrasound, 2010.

4.2. Recommended Exposure Limits

A Public Health England report notes that there are no specific standards covering consumer products that generate or emit ultrasound.[3] Those reports which do exist make recommendations regarding occupational exposure.

The following is a summary of recommended occupational exposure limits adapted from a 1991 review by the Environmental Health Directorate of Canada, which has since been widely cited: [4]

Report	Recommended 1/3-Octave Band Limit (dB SPL)		
	16kHz	**20kHz**	**25kHz**
Japan (1971)	90	110	110
Acton (1975)	75	75	110
USSR (1975)	85	110	110
Sweden (1978)	-	105	110
USA (ACGIH, 1989) [5]	80	105	110
USA (IRPA, 1984) [6]	-	75	110

Table 1. Hearing threshold and physiological effects as a function of sound frequency.[7]

There is good consistency among the recommendations for the 16 kHz band and again for the 25 kHz band. In both of these bands, the sensitivity of the human ear changes relatively slowly with frequency. There is a wide range in recommended exposure limits for the 20kHz band, however, driven by the dramatic change in audibility between the lower and upper halves of the band.

Having reviewed these data Health Canada opted to apply a 75dB limit for the 20kHz 1/3-octave band, following the IRPA's lead. In reducing their recommended limit from its previous value of 110 dB, Health Canada noted the overlap of the lower end of the 20kHz 1/3 octave band with the audible frequency range.

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[3] Public Health England RCE-14: Health Effects of Exposure to Ultrasound and Infrasound, 2010.
[4] Environmental Health Directorate of Canada: Guidelines for the safe use of ultrasound: part II—industrial and commercial applications. Safety Code, 24 (1991).
[5] American Conference of Governmental Industrial Hygienists (ACGIH): Threshold Limit Values and Biological Exposure Indices for 1988–1989. ACGIH, Cincinnati, OH (1989).
[6] International Radiation Protection Association (IRPA): Interim guidelines on limits of human exposure to airborne ultrasound. Health Phys., 46 (1984), pp. 969-974.
[7] Public Health England RCE-14: Health Effects of Exposure to Ultrasound and Infrasound, 2010.

A more recent review of recommended occupational exposure limits has been provided by the Institute of Sound and Vibration Research.[8] This draws a distinction between "very high frequencies" (VHF; 10-20 kHz) and ultrasonic frequencies (>20 kHz). This review notes:

> *From the evolution of maximum permissible levels (MPLs) as seen here, it is plain that the limiting level for very high frequencies, up to 20kHz, was set low, at 75-85 dB, to avoid unpleasant subjective effects in young workers.*

It goes on to note that:

> *For ultrasonic components, MPLs in the range 105 – 115 dB were established to avoid the possibility of hearing damage …*

This is supported by the Health Canada report, which notes that "*Sound pressure levels below 120 dB at ultrasonic frequencies have not been demonstrated to cause hearing loss.*".

In summary, the 20kHz 1/3-octave band is a blunt instrument, lumping together VHF and ultrasonic frequencies which have very different audibility. Proposed occupational exposure limits for the band vary widely as a result.

There is however agreement in the literature that ultrasonic emissions above 20kHz pose a risk to hearing only above 105 dB or more, with the lower recommended limit of 75 dB adopted by the IRPA being driven by the subjective effects of frequencies *below* 20kHz.

4.3. Comparison with disc pump emissions

Typical ultrasound emission data were obtained from XP Series pumps mounted on the Evaluation Kit PCB with tubes connected, as shown in Figure 3. This is representative of typical mounting conditions within products.

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[8] Institute of Sound and Vibration Research: Exposure Limits for Airborne Sound of Very High Frequency and Ultrasonic Frequency. ISVR Technical Report No 334, April 2013.

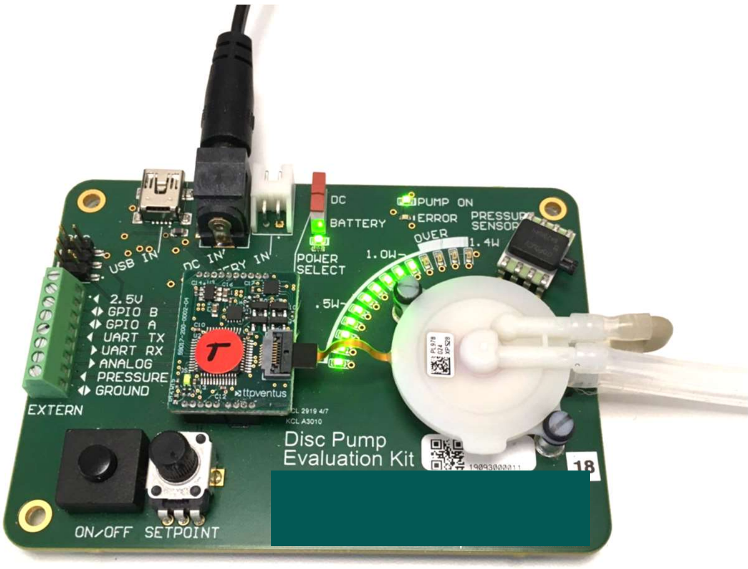

Figure 3. Piezoelectric disc pump evaluation kit configuration used for assessing typical noise emissions from Disc Pumps.

Average and maximum SPL measurements from five pumps, operating at 1W continuous power, are shown in Table 2. Sound pressure level measurements for XP Series pumps under different load conditions. Table 2. These sound levels fall well below the lowest levels associated with hearing damage and are also below the range associated with subjective effects.

	Stall	Vacuum	Free-Flow
Average (dB SPL)	67.1	64.5	59.6
Max (dB SPL)	69.7	68.5	64.2

Table 2. Sound pressure level measurements for XP Series pumps under different load conditions.

It is worth noting that without tubing connected to the pumps sound emissions are higher (an average of 75.5 dB under free-flow conditions, with a maximum of 79.6 dB). Again, these levels fall well below the lowest levels associated with hearing damage but are now partly inside the range that is associated with subjective effects for frequencies below 20kHz. In practice however, pumps are connected to a load of some form, and so these higher sound levels should not be experienced.

4.4. Other Considerations

4.4.1. Intermittent use

The IRPA's recommended occupational exposure limits are based on continuous exposure. Where exposure is for shorter periods, their recommended limits increase as follows:

Exposure per day	Increase to limit
2 – 4 hrs	+3 dB
1 – 2 hrs	+6 dB
Less than 1 hr	+9 dB

4.4.2. Consumer Exposure

The vast majority of published recommendations relate to occupational exposure, often relating to industrial or medical environments. The IRPA recommends slightly lower limits for public exposure.

Report	Recommended 1/3-Octave Band Limit	
	20kHz	25kHz
USA (IRPA)	-5 dB	-10 dB

4.5. Summary

Recommended continuous occupational exposure limits for the 20kHz 1/3 octave band vary widely, driven by the rapidly changing sensitivity of the human ear across this frequency range.

Typical Disc Pump emissions fall well below the lowest sound levels known to cause hearing damage within this band, and in normal use they also fall below levels associated with subjective effects. Further confidence is provided by the fact that subjective effects are associated with frequencies in the lower half of the 20 kHz band – while Disc Pumps operate above 20kHz, where the human ear is much less sensitive.

5. Mitigating Ultrasound Emissions

The results reported in §4.3 are for the "open" system shown in Figure 3 – i.e. a pump mounted on a PCB with no further shielding of any kind. In practise ultrasound emissions from products using Disc Pumps can be reduced below these levels through:

i. Running pumps intermittently
ii. Running pumps at reduced powers
iii. Appropriate product casework design, and use of sound-absorbing materials

5.1. Intermittent operation

As described in §4.4.1, the effects of ultrasound are reduced where the duration of the exposure is limited. Whether intermittent operation is practical will depend on the details of the application.

5.2. Operation at reduced power

The noise output of a Disc Pump depends on its operating power, however other factors such as operating temperature also affect noise output at a given power. Measurements show a typical reduction of 10dB in noise output when operating power is reduced from 1W to 0.1W, for example. Again, the practicality of this will depend on the details of the application.

5.3. Attenuation by Casework

Products using Disc Pumps will generally have casework of some kind, and this can provide attenuation of pump ultrasound emissions.

It is important to note that ultrasound can reflect from surfaces, and so the details of surfaces around the pump (PCBs, casework interior, etc) can affect acoustic emissions. Having flat, hard surfaces on either side of the pump may lead to higher noise emissions, for example.

Conversely, ultrasound emissions can be reduced by having soft, absorbing surfaces facing the pump. As an example, the SPL measured at 30cm from an evaluation kit board was found to reduce by ~3dB, when a small piece of 0.8mm silicone foam was inserted between the pump and the PCB.[9]

[9] HT-800 Medium Cellular Silicone, made by Rogers Corporation.

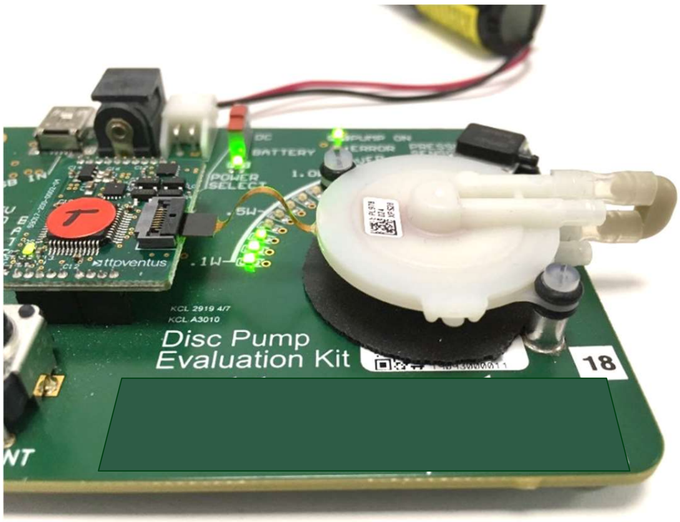

Figure 4: Ventus Evaluation Kit with silicone foam sheet inserted between pump and PCB

Adding a second sheet of silicone foam above the pump was found to further reduce ultrasound emissions.

What can be achieved with these sorts of measures will depend on the details of the application, including pump mounting and casework design. Based on our results, it is generally possible to reduce ultrasound emissions by 10dB or more by employing modest measures of this kind.

6. Support

The Lee Company Website (www.theleeco.com) provides advice on:

- Getting Started
- Applications
- Development Process
- Downloads (including datasheets, application notes, case studies and 3D models)
- Frequently Asked Questions

The Lee Company is happy to discuss next steps beyond prototyping, including system design. If you would like to discuss this with us, or for any other additional support, please contact us your Lee Sales Engineer.

7. REVISION HISTORY

Date	Version	Change
2 May 2024	3	Reformat
18 August 2023	2	Rebranding
22 December 2021	1	Initial release