

AMERICAN GEAR MANUFACTURERS ASSOCIATION

Gear Sound Manual

Part I - Fundamentals of Sound as Related to Gears

Part II - Sources, Specifications and Levels of Gear Sound

Part III - Gear Noise Control

AGMA 914-B04



AGMA INFORMATION SHEET

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American
Gear
Manufacturers
Association

Gear Sound Manual
Part I - Fundamentals of Sound as Related to Gears
Part II - Sources, Specifications and Levels of Gear Sound
Part III - Gear Noise Control

AGMA 914-B04
[Revision of AGMA 299.01]

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ABSTRACT

Noise measurement and control on gear driven equipment is dependent upon the individual characteristics of the prime mover, gear unit and driven machine, as well as their combined effects as a system in a particular acoustical environment.

Because of the wide variation of gear driven systems and acoustical environments, this manual attempts to indicate certain areas where special considerations might be necessary, and must be agreed upon between purchaser and the gear manufacturer, when discussing gear sounds.

The information is arranged in three parts. Part I presents the fundamentals necessary to understand sound as related to gears. Part II describes the sources, specifications and levels of gear sound. Reduction or control of noise, as addressed in Part III, requires attention to connecting equipment and the acoustical environment, as well as the gear unit.

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Foreword

[The foreword, footnotes and annexes, if any, in this document are provided for informational purposes only and are not to be construed as a part of AGMA Information Sheet 914-B04, *Gear Sound Manual: Part I – Fundamentals of Sound as Related to Gears; Part II – Sources, Specifications and Levels of Gear Sound; Part III – Gear Noise Control.*]

Concern with industrial noise created a need for a sound standard on all types of products. Noise measurement, control and attenuation on gear driven equipment is dependent upon the individual characteristics of the prime mover, gear unit, and driven machine – as well as their combined effects as a system in a particular acoustical environment.

Proper assessment of these considerations is essential for realistic determination of acoustic values. The knowledge and judgment required to properly evaluate the various factors comes primarily from years of accumulated experience in designing, manufacturing, and operating gear units. For this reason, the detailed treatment of the testing and resultant conclusions for specific product applications is best accomplished by experts in the field.

The complexity makes most sound standards difficult to apply or interpret properly. The AGMA Acoustical Technology Committee developed the *Gear Sound Manual* 299.01 to provide improved communication between project engineers, gear manufacturer, and user in the areas of *Fundamentals of Sound as Related To Gears* (Part I), *Sources, Specifications and Levels of Gear Sound* (Part II), and *Gear Noise Control* (Part III).

This Information Sheet was originally issued as three separate documents: AGMA 299.01, Section I, *Fundamentals of Sound as Related to Gears*; AGMA 299.01, Section II, *Sources, Specifications and Levels of Gear Sound*; and AGMA 299.01 Section III, *Gear Noise Control*. Section I was approved by the membership in January 1978, Section II was approved in October 1978, and Section III was approved in October 1978. Combining the three entitled, AGMA SOUND MANUAL, was approved by the AGMA Technical Division Executive Committee in October 1987.

The first draft of AGMA 914-B04 was made in November, 2002. It combines all three parts into one document with three clauses, updates references, and adds a subclause on Fast Fourier Transform analysis. It was approved by the AGMA membership in March, 2004.

Suggestions for improvement of this document will be welcome. They should be sent to the American Gear Manufacturers Association, 500 Montgomery Street, Suite 350, Alexandria, Virginia 22314.

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Gear Sound Manual: Part I – Fundamentals of Sound as Related to Gears

1.1 Scope

The purpose of this manual is to establish a common base for communications pertaining to various types of gear units in differing applications and to encourage the maximum practical degree to uniformity and consistency between sound measurement practices within the gear industry.

Because of the wide variation of gear driven systems and acoustical environments, this manual attempts to indicate certain areas where special considerations might be necessary and must be agreed upon

between purchaser and gear manufacturer when discussing gear sounds.

1.2 References

The following standards contain provisions which are referenced in the text of this information sheet. At the time of publication, the editions indicated were valid.

AGMA 913-A98, *Effect of Lubrication on Gear Surface Distress*

ANSI/AGMA 1012-F90, *Gear Nomenclature, Definitions Of Terms With Symbols*

ANSI/AGMA 6025-D98, *Sound for Enclosed Helical, Herringbone and Spiral Bevel Gear Drives*

1.3 Symbols and definitions

The terms used, wherever applicable, conform to ANSI/AGMA 1012-F90.

NOTE: The symbols and definitions used in this standard may differ from other AGMA standards. The user should not assume that familiar symbols can be used without a careful study of their definitions.

The symbols and terms, along with the clause numbers where they are first discussed, are listed in alphabetical order by symbol in table 1-1.

Table 1-1 - Symbols and definitions

Symbol	Definition	Units	First referenced
a_i	Sound pressure level from a single source or octave	dB	Eq 1.5
f	Frequency	Hz	Eq 1.1
L_p	Sound pressure level	dB	1.5.2.1
L_w	Sound power level	dB	1.5.2.2
N	Number of single levels investigated	--	Eq 1.5
p	Sound pressure being measured	$\mu\text{N/m}^2$	Eq 1.2
p_o	Sound pressure, reference	$\mu\text{N/m}^2$	Eq 1.2
v	Velocity	--	Eq 1.1
W	Sound power	picowatt	1.5.2.2
W_o	Sound power reference	picowatt	1.5.2.2
λ	Wavelength	--	Eq 1.1

1.4 What is sound?

Sound can be defined as the variations in pressure, stress, or particle displacement of a medium, or the sensation of hearing resulting from these variations. These variations propagate through the medium to a receiver (ear, pick-up, transducer, etc.). Therefore, there are three elements of sound: source, transmitting medium and receiver.

When an object vibrates, a disturbance is caused in the surrounding medium. This disturbance causes a pressure oscillation, which travels through the medium to the receiver, where it is transformed back into a vibration. This receiver may either cause an auditory sensation or excite some type of read-out instrumentation.

The transmission of pressure variations is referred to as a sound wave. A sound wave has the following basic characteristics:

- amplitude;
- frequency;
- velocity;
- wavelength;
- waveform.

1.4.1 Amplitude

Amplitude is the amount of variation in the pressure reading of the medium, relative to a standard reference pressure. Amplitude determines the energy level or strength of the sound, normally expressed in terms of a decibel level.

1.4.2 Frequency

Frequency is the number of variations in the amplitude per a given period of time, normally expressed in Hertz (cycles per second).

1.4.3 Velocity

Velocity of the sound is the speed of the wave, and is a function of the elastic modulus and the mass density of the medium.

1.4.4 Wavelength

Wavelength is the distance between adjacent waves of the same frequency. The relationship of frequency, velocity, and wavelength is expressed by:

$$\lambda = \frac{v}{f} \quad (1.1)$$

where

- λ is wavelength;
- v is velocity;
- f is frequency.

1.4.5 Waveform

Waveform defines the type of sound wave, i.e., whether the wave is simple (sinusoidal), complex deterministic (periodic), or a complex random wave consisting of multiple frequencies, harmonics, random pulses, etc. See figure 1-1.

1.5 Description of sound

1.5.1 Description

Sound is commonly measured or described by one or more of the following characteristics:

Level

- sound pressure level;
- sound power level.

Frequency content

- A, B, and C weighing networks;
- octave and 1/3 octave band filters;
- narrow band filters.

Descriptive properties

- sound intensity;
- loudness;
- pitch;
- tone;
- directivity.

1.5.2 Level

The level of sound is normally described in terms of either sound pressure level at a given distance from the source or sound power level. In each of these, the desired quantity (pressure or power) is expressed in the numerator of a ratio with the reference level as the denominator. Because of the extremely wide range of levels measured (very small to extremely large) in everyday environments, both pressure and power ratios are expressed by logarithmic scales.

1.5.2.1 Sound pressure level, L_p

Sound pressure level, L_p , expressed in decibels, is 20 times the logarithm to the base 10 of the ratio of

the sound pressure being measured to the reference sound pressure.

$$L_p = 20 \log_{10} \frac{p}{p_0}, \text{ dB (re } 20 \mu\text{N/m}^2) \quad (1.2)$$

where

- p is sound pressure being measured, $\mu\text{N/m}^2$;
 p_0 is reference sound pressure, $20 \mu\text{N/m}^2$.

The reference sound pressure, p_0 , is internationally accepted as 20 micro Newtons/meter squared, which is about the threshold of normal hearing at a frequency of 1000 Hz. All sound measuring instruments respond to sound pressure.

Example: The sound pressure near a punch press is measured as being 0.0025 psi. What is the sound pressure re $20 \mu\text{N/m}^2$ in dB?

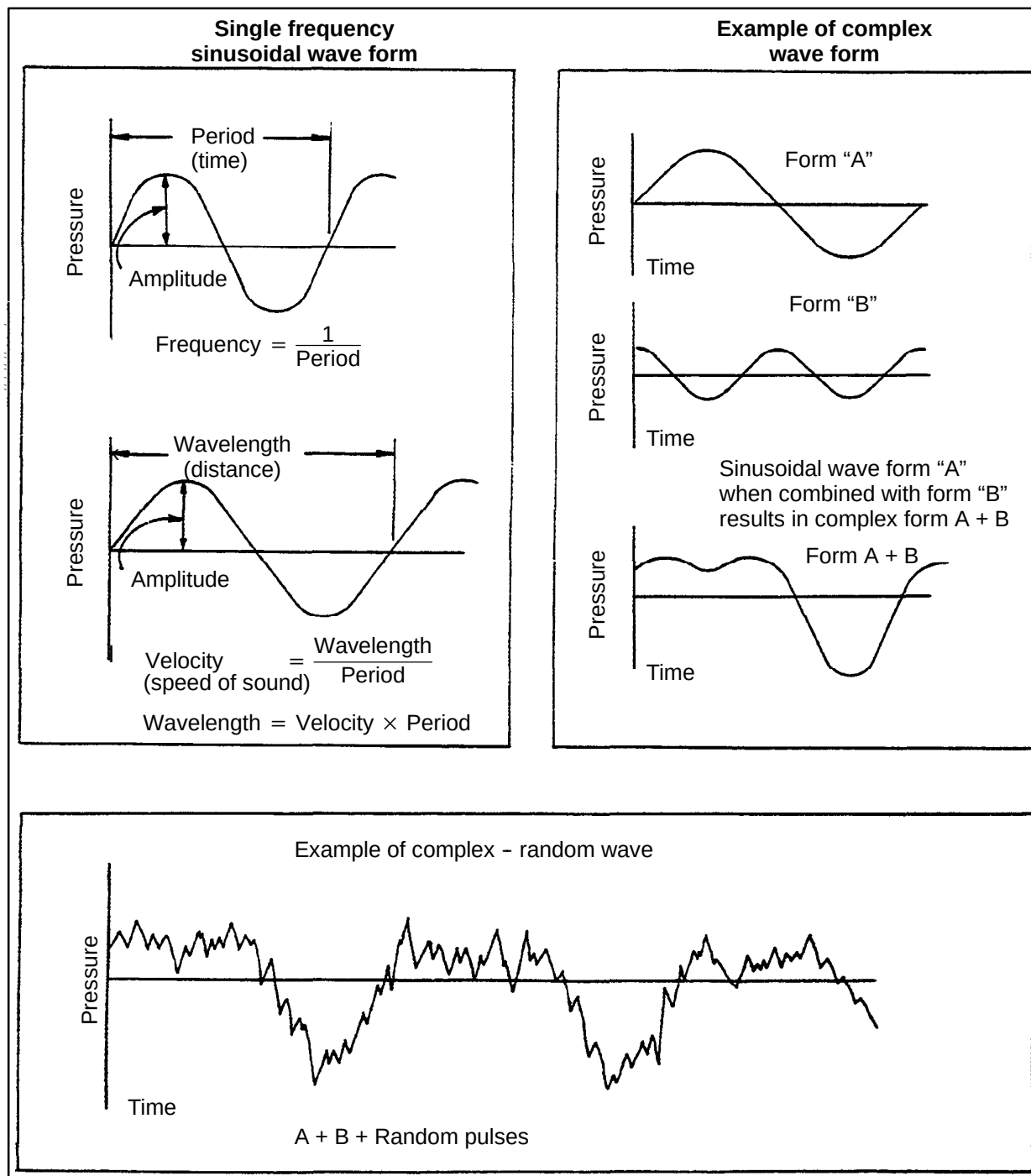


Figure 1-1 - Sound wave forms

Since $1.0 \text{ psi} = 6890 \text{ N/m}^2$, then $0.0025 \text{ psi} = 17.225 \text{ N/m}^2$.

$$\begin{aligned} L_p &= 20 \log_{10} \left(\frac{17.22 \text{ N/m}^2}{20 \mu\text{N/m}^2} \right) \\ &= 20 \log_{10} (8.612 \times 10^5) \\ &= 118.7 \text{ dB (re } 20 \mu\text{N/m}^2) \end{aligned} \quad (1.3)$$

So we would commonly say the noise of the punch press is 119 dB.

1.5.2.2 Sound power level, L_w

Sound power level, L_w , is the ratio, expressed in decibels, of the sound power under consideration to the reference sound power, one picowatt (10^{-12} watt).

$$L_w = 10 \log_{10} \frac{W}{W_0}, \text{ dB (re } 10^{-12} \text{ watt)} \quad (1.4)$$

where

W is sound power under consideration, picowatt;

W_0 is reference sound power, picowatt.

Sound power cannot be measured directly. It can be obtained only by calculation after having measured sound pressure levels in a known acoustical environment (i.e., anechoic chambers, reverberant rooms, etc.).

1.5.3 Frequency content

The frequency content of a sound is normally described as a particular frequency or by the level content in a band of frequencies.

1.5.3.1 A, B and C weighing networks

The frequency response of the human ear is not as good as a sound level meter. Therefore, various weighing networks (filters) have been established so that the objective meter measurement will come close to indicating what the ear hears. Figure 1-2 shows the attenuation of the A, B and C weighing scales of a sound level meter. The A scale is a filtering system that roughly matches the human ear's response at sound levels below 55 dB. The B scale roughly matches the ear at levels between 55 dB and 85 dB, and the C scale is to match above 85 dB. However, the A scale (sound pressure level measured in dBA) has received prominence due to its use in OSHA, for measuring levels up to 115 dB. It

is interesting to note the tremendous attenuation the A scale performs on low frequencies. At about 95 Hz, for example, there is about a 20 dB attenuation. Only 1/10 of the actual sound is indicated on the meter. Therefore, gears generating low frequency sound are more likely to pass a dBA specification, and be less annoying to the ear. AGMA sound standards use an A weighted sound level (dBA) as a common indication of performance. See figure 1-3.

1.5.3.2 Octave and 1/3 octave band filter

Another filtering system often used in the measurement of sound is the octave and 1/3 octave bands. These are discrete filters which only register a limited range of frequencies. The octave and 1/3 octave bands are used for analytical work and are usually specified by their center frequencies. See table 1-2. The 63 Hz octave band to the 8000 Hz octave band are most commonly used in industry specifications.

1.5.3.3 Narrow band filters

A narrow band filter (spectrum analyzer) is similar to octave band filters, however, the band filter is greatly reduced in width to allow better resolution of component frequencies in a noise spectrum. A narrow band filter may have a bandwidth of only 2 Hz. Real time analyzers are a special form of narrow band filter that enables the investigator to look at all bands in an instant, instead of sweeping through each band slowly.

1.5.4 Descriptive properties

The characteristics described are the ones which must be investigated properly in order to obtain an accurate description of a generated sound level and to be able to prescribe proper corrective measures for reduction of excessive levels.

1.5.4.1 Sound intensity

Sound intensity is the quotient, expressed in watts per square meter, obtained when the average rate of sound energy flowing in a specified direction is divided by the area, perpendicular to that direction toward which it flows.

1.5.4.2 Loudness

Loudness is the attribute of sound intensity which depends primarily on the sound pressure. Loudness is typically ranked on a scale ranging from soft to loud. See figure 1-3.

A, B, and C electrical weighting networks for the sound-level meter

These numbers assume a flat, diffuse-field response for the sound-level meter and microphone

Frequency, Hz	A-weighting relative response, dB	B-weighting relative response, dB	C-weighting relative response, dB	Frequency, Hz	A-weighting relative response, dB	B-weighting relative response, dB	C-weighting relative response, dB
10.0	-70.4	-38.2	-14.3	500	-3.2	-0.3	0.0
12.5	-63.4	-33.2	-11.2	630	-1.9	-0.1	0.0
16.0	-56.7	-28.5	-8.5	800	-0.8	0.0	0.0
20.0	-50.5	-24.2	-6.2	1 000	0.0	0.0	0.0
25.0	-44.7	-20.4	-4.4	1 250	0.6	0.0	0.0
31.5	-39.4	-17.1	-3.0	1 600	1.0	0.0	-0.1
40.0	-34.6	-14.2	-2.0	2 000	1.2	-0.1	-0.2
50.0	-30.2	-11.6	-1.3	2 500	1.3	-0.2	-0.3
63.0	-26.2	-9.3	-0.8	3 150	1.2	-0.4	-0.5
80.0	-22.5	-7.4	-0.5	4 000	1.0	-0.7	-0.8
100.0	-19.1	-5.6	-0.3	5 000	0.5	-1.2	-1.3
125.0	-16.1	-4.2	-0.2	6 300	-0.1	-1.9	-2.0
160.0	-13.4	-3.0	-0.1	8 000	-1.1	-2.9	-3.0
200.0	-10.9	-2.0	0.0	10 000	-2.5	-4.3	-4.4
250.0	-8.6	-1.3	0.0	12 500	-4.3	-6.1	-6.2
315.0	-6.6	-0.8	0.0	16 000	-6.6	-8.4	-8.5
400.0	-4.8	-0.5	0.0	20 000	-9.3	-11.1	-11.2

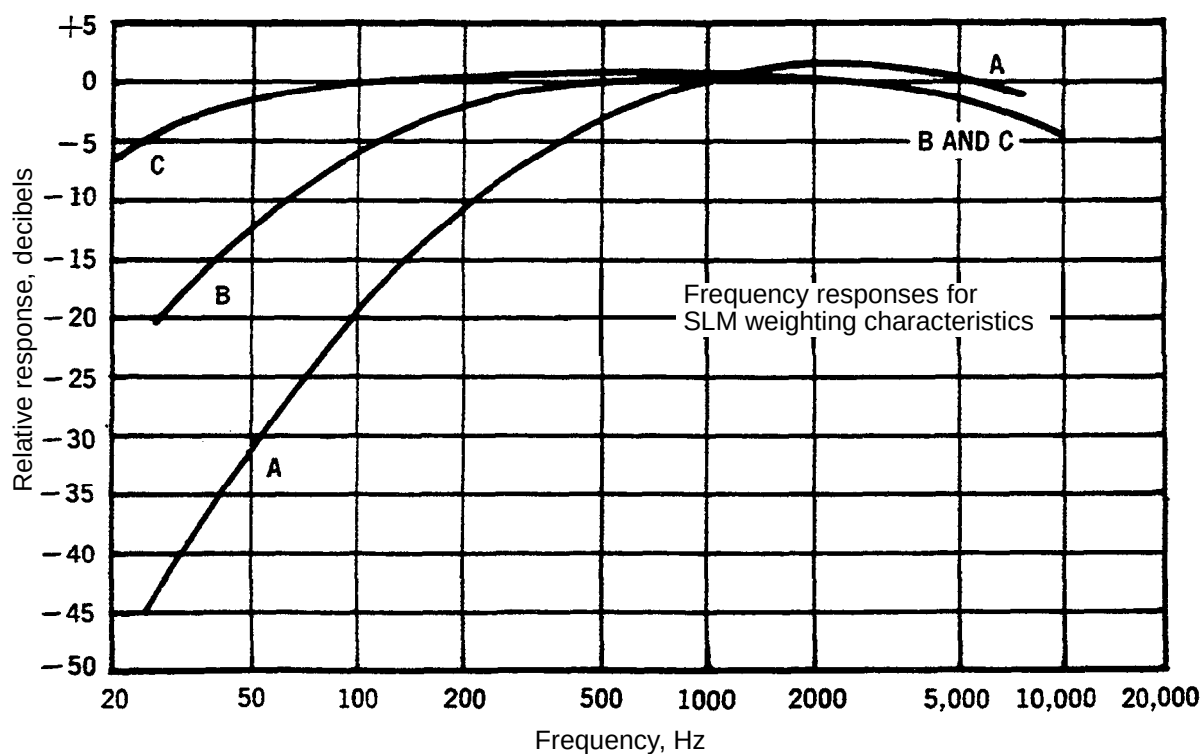


Figure 1-2 - Frequency responses

1.5.4.3 Pitch

Pitch is the psychophysical attribute of sound corresponding approximately to frequency by which sounds may be ordered from low to high. Pitch depends primarily upon the frequency of the sound,

but it also depends upon the sound pressure and wave form.

1.5.4.4 Tone

Tone is an auditory sensation of pitch. There are two types of tones: a pure tone and a complex tone. A

pure tone is created by a simple sinusoidal function. A complex tone is created by a combination of simple sinusoidal functions. Most of the sound which is investigated around gear units is a combination of complex tones and random noise.

1.5.4.5 Directivity

Directivity describes the directionality of sound in a

field. Sound does not propagate equally in all directions except in a textbook free field case. In measuring sound pressure level, directionality must be taken into consideration. A gear unit against a wall radiates a higher level of sound in a given direction away from the wall than an isolated unit removed from reflecting surfaces.

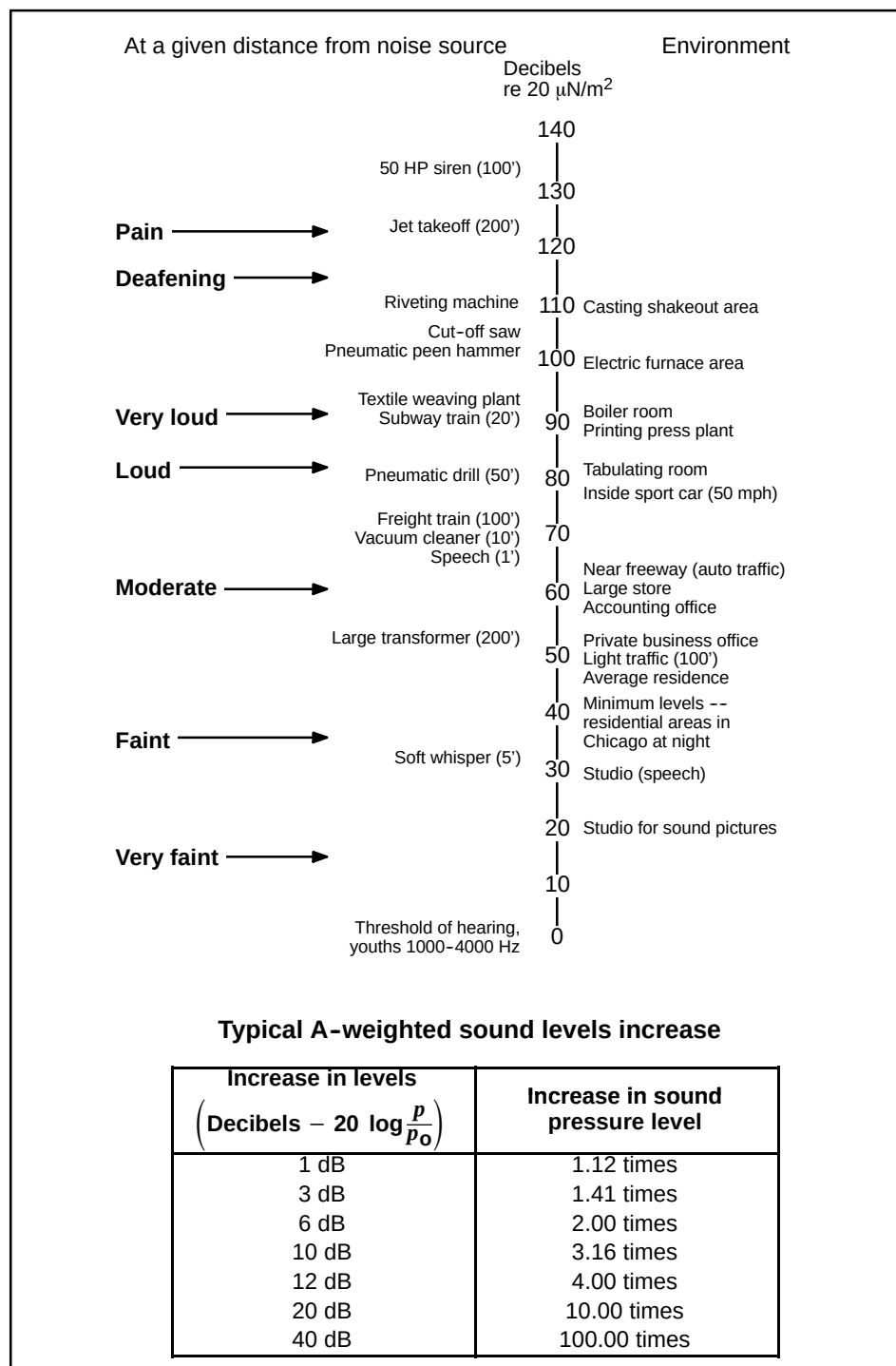


Figure 1-3 - Typical A-weighted sound levels

Table 1-2 - Center and approximate cut-off frequencies for standard set of contiguous-octave and one-third-octave bands covering audio frequency range

Band	Frequency, Hz					
	Octave			One-third octave		
	Lower band limit	Center	Upper band limit	Lower band limit	Center	Upper band limit
12	11	16	22	14.1	16	17.8
13				17.8	20	22.4
14				22.4	25	28.2
15	22	31.5	44	28.2	31.5	35.5
16				35.5	40	44.7
17				44.7	50	56.2
18	44	63	88	56.2	63	70.8
19				70.8	80	89.1
20				89.1	100	112
21	88	125	177	112	125	141
22				141	160	178
23				178	200	224
24	177	250	355	224	250	282
25				282	315	355
26				355	400	447
27	355	500	710	447	500	562
28				562	630	708
29				708	800	891
30	710	1 000	1 420	891	1 000	1 122
31				1 122	1 250	1 413
32				1 413	1 600	1 778
33	1 420	2 000	2 840	1 778	2 000	2 239
34				2 239	2 500	2 818
35				2 818	3 150	3 548
36	2 840	4 000	5 680	3 548	4 000	4 467
37				4 467	5 000	5 623
38				5 623	6 300	7 079
39	5 680	8 000	11 360	7 079	8 000	8 913
40				8 913	10 000	11 220
41				11 220	12 500	14 130
42	11 360	16 000	22 720	14 130	16 000	17 780
43				17 780	20 000	22 390

1.6 Sound or noise?

The differentiation between sound and noise can be defined simply: sound is a variation in pressure; noise is undesired sound. Noise also implies undesired frequencies which tend to mask useful information, causing possible misrepresentation of actual sound characteristics. Examples of noises extraneous to gear sound measurement are lubrication pump noise, air-drill noise, 60 cycle hum, instrumentation, electrical noise, etc.

Sound measurement and analysis are required to determine what sound is typically generated and what sound is undesired noise. This analysis is accomplished by the use of a sound analyzer. A sound analyzer is an instrument which displays

sound waves in the form of rms levels at various frequencies or frequency bands. Using an analyzer will help separate undesired frequencies from the sound spectrum and contribute to an accurate interpretation of sound data. The bandwidth of the analyzer governs the amount of useful data displayed for analysis. The narrower the bandwidth, the more discrete frequency information available, the easier it becomes to identify extraneous noise frequencies from the other generated sound in a gear driven system.

In all possible cases, the elimination of unwanted noise in the area under investigation should be carried out before proper gear sound analysis is initiated. This will make the engineer's job of

analyzing the data much easier and will enable him to give better results.

1.7 Generation of sound in gear units

The sounds generated during gear unit operation can be from one or more of the following major sources:

- gear dynamics;
- bearing dynamics;
- coupling noises;
- system resonance or critical speeds;
- accessories such as fans, lubrication systems, etc.

Sound generation in gears is related to design tolerances and operation. The mating accuracy of a gear set must be maintained, commensurate with the desired operation. Gear sound is often generated by the mesh action of the teeth. If the teeth have irregularities in their profile or spacing, noise may be generated at the frequency of the irregularities. One must understand that a 100% accurate theoretical tooth profile will still generate sound due to the dynamics of gear mesh. Improper lubrication may allow noise to be generated in the mesh. The sounds generated will often be at the mesh frequency (i.e., the frequency of rotation times the number of teeth on the rotor), harmonics of mesh frequency, or at sideband frequencies (mesh frequency plus and minus pinion or gear rotational frequencies).

Sound in ball and roller bearings can be generated by the irregularities in the bearing elements, friction, deflections under load, misalignments, loose cages and races, windage, roller skewing and/or skidding, etc. Misalignments and deflections under load are the major causes of antifriction bearing noise.

Couplings may produce noise due to windage. Exposed bolts, exposed holes and high velocity surfaces can all add to the ability of a coupling to generate noise due to windage. The windage shows up as a rotational frequency and multiples of rotational frequency, depending on the number of exposed bolts and exposed holes.

System resonances and critical speed generate sound in gear units. The structural resonant frequencies of the casing and the baseplate can be excited by internally generated frequencies (tooth mesh) to

produce noise. Care must be taken to determine the natural frequencies of support structures to ensure that the rotational frequency and other generated frequencies are not coincident to, or a multiple of, natural frequencies. Likewise, lateral and torsional natural frequencies in the rotating system may be excited to produce noise if they are too close to a generated frequency or its harmonics.

Often, other equipment is required for proper operation of a gear unit. Accessories such as cooling fans and lubrication systems (pumps, motors, relief valves, etc.) can be sources of noise which may appear to be generated by the gear units.

1.7.1 Overall sound level

All of these sources as well as extraneous noise from the surrounding environment (background noise) add up to the overall sound level in the area of the gear unit. The interrelationship between them helps to define the sound level. The overall level is determined by the addition of different generated levels by the following expression:

$$L_p = 10 \log_{10} \sum_{i=1}^N 10^{(0.1a_i)} \quad (1.5)$$

where

L_p is sound pressure level, dB;

a_i is sound pressure level from a single source or octave;

N is number of single levels investigated.

In an octave band analysis, N is the number of octaves.

1.7.2 Example 1

The installation in figure 1-4 shows a motor, parallel shaft double increasing gear unit, and a compressor in an industrial plant environment. The sound of each piece of equipment was measured by its manufacturer to have the listed sound levels at the operator location shown. Totaling the levels by the formula gives an expected level at the operator of 94 dBA. Actual measurement after installation indicated 95 dBA at full load.

Therefore, a means of adding or subtracting sound generated from different sources is also available. Any school student will tell you that $(82 + 88 = 89)$ is an invalid equation. However, if we state that in the same environment $82 \text{ dB} + 88 \text{ dB} = 89 \text{ dB}$ we would be correct. Figure 1-5 shows a chart which can be used to assist in adding and subtracting sound pressure levels in dB units of measure.