WHITE PAPER

How Does Your Gearbox Sound?

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Introduction

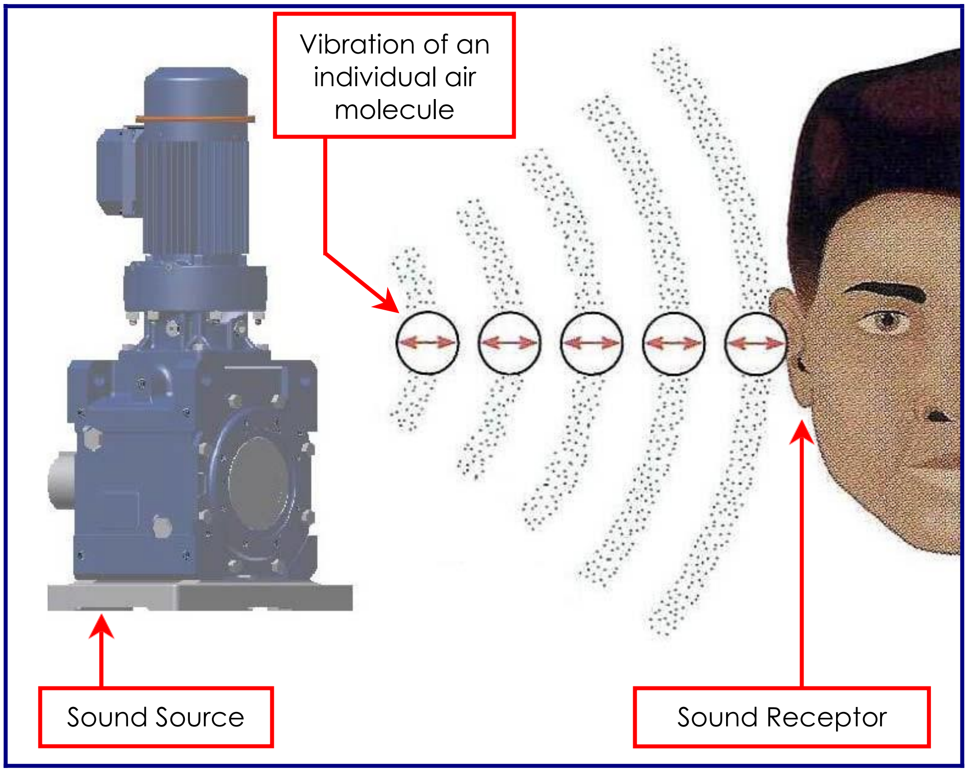
Sound can be a very subjective thing. What may sound “unusual” to one individual may very well sound “normal” to another. As a method of diagnosing a potential problem with a gearbox or gearmotor, the sound coming from it should not solely be relied upon to determine whether-or-not a problem exists. The measurement of sound, however, may very well provide valuable clues to the gearbox operator, the equipment manufacturer, and/or the gearbox supplier as to the condition of the unit in question. This article will briefly explore the fundamentals of sound and how it is measured. Additionally, a method of isolating sound from ambient conditions will be addressed.

What is Sound?

In and of itself, the study of sound is a very complex science. To be sure, careers have been made and volumes have been written specifically in relation to the science of sound. Such a detailed analysis goes beyond the scope of this article but it is imperative to distinguish the difference between “sound” and “noise”. Many people use these terms interchangeably but, in context, they are different from one another.

Strictly speaking, **sound** is defined as the back-and-forth vibration of the particles in a medium (such as air, water, or a solid) that are created when a traveling wave passes through the medium. By virtue of this back and forth motion, a pressure wave (sound pressure) is created which is dependent upon the amount of air pressure fluctuation the sound source creates. Or, expressed a little less “technically”: When something vibrates it causes the particles near it to vibrate as well. These particles likewise bounce “into” and “away from” each other forming high and low pressure waves that form the sound that we hear when these pressure waves reach our ears.

Intuitively it can be inferred from this that there exists three elements to sound: (1) a sound source or generator – a gearbox for example; (2) a medium – typically air for gearbox applications and (3) a sound receptor – the human ear for instance.



Noise, on the other hand, is simply defined as an undesirable sound.

With these two definitions in mind, it is easy to see how discussions on how something sounds can be so difficult. Looking back on my younger years, I can still hear my father telling me to "Turn that noise down!" as I listened to my favorite record on the stereo. Noise to him, music to me … subjective indeed.

How Sound is Measured

Sound pressure is usually expressed in units of Newtons per square meter (N/m^2) also known as Pascal or simply "Pa". The lowest sound pressure that we as humans can hear is approximately 0.00002 Pa. Conversely, sound pressures of approximately 20 Pa fall into the range of human discomfort. Thus, humans have the ability to hear sounds across a very wide range of sound pressure values. Given this broad range in which sound pressure can be perceived by the human ear, it is more convenient to refer to **sound pressure levels** when addressing questions of sound.

The following expression of sound pressure level uses mathematical logarithms to compare a sound pressure against an established sound pressure standard.

$$\text{Sound Pressure Level} = L_P = (20\text{dB})\left(\log \frac{p}{p_0}\right)$$

In this equation, “p” is the sound pressure of the sound wave and “p_0” is a standard reference sound pressure (0.00002 Pa = 20 µN/m^2). The stated value for “p_0” is used because it is near the lower limit of human audibility. While mathematically dimensionless, the resulting value is referred to as a decibel (dB)

– chosen to recognize the work of Alexander Graham Bell – the Scottish born physicist credited with developing the first functional telephone.

In this regard, weighing scales have been developed which, when applied to the measured value, are intended to approximate what the human ear is hearing. These scales are referred to as the A, B, and C scales. Typically in industry, the “A” weighing filter is applied in sound pressure level equipment and discussion. This is due to the fact that people hear high frequency sounds better than low frequency sounds and the applied “A” weighing factor deemphasizes the lower frequencies from a reading. When representing results gathered from sound measurements, it is a common practice to include the scale setting which was used to measure the data – i.e.: dB**A** represents a sound pressure level measured with the “A” weighing factor applied.

For comparative purposes, the following table details some common sound pressure levels along with their corresponding sound pressures:

Sound	Typical Sound Pressure Level (dBA)	Sound Pressure (N/m^2)
Threshold of hearing	0	0.00002
Rustle of Leaves	10	0.00006
Whisper (at 1 meter)	20	0.0002
Office Area	50	0.006
Normal Conversation (at 1 meter)	60	0.02
Sumitomo 4B125 Bevel Buddybox, 60:1 Reduction Ratio, 5 HP motor	67	0.045
Jackhammer (at 1 meter)	90	0.6
Rock Concert	110	6.3
Threshold of Pain	120	20
Jet Engine (at 50 meters)	130	63

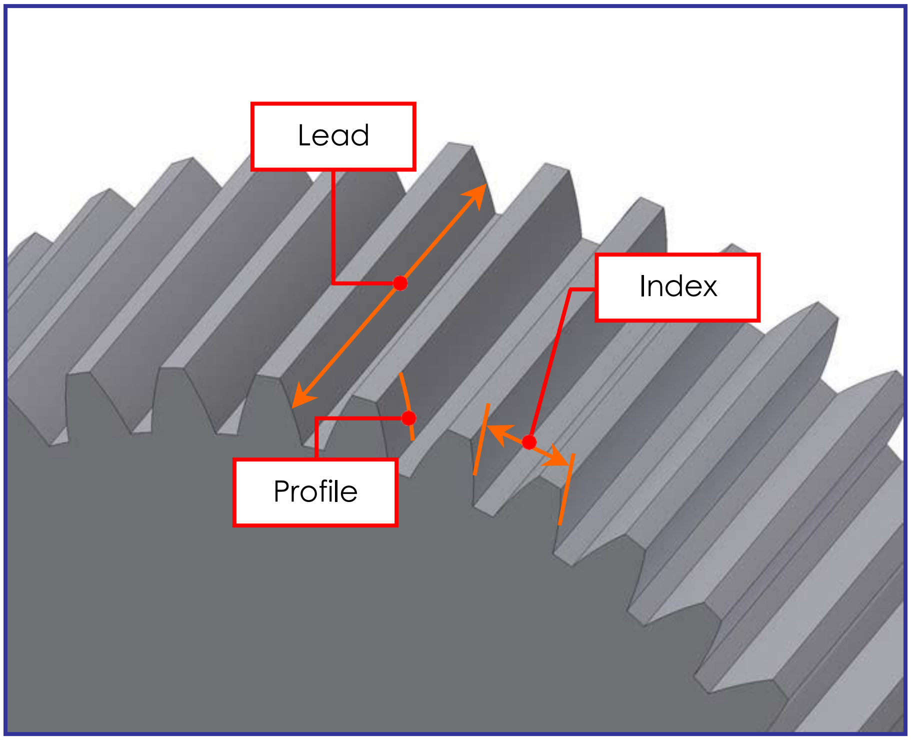
In terms of the physical measurement of sound, many companies offer specialized equipment intended solely to measure sound pressure levels. The size and functionality of such specialized equipment varies greatly and, as a result, the cost of such equipment varies greatly as well. In an industrial environment, it is common to utilize hand-held meters for such evaluations. These hand-held meters are often called Decibel (or simply dB) Meters and they provide a simple, portable, and economical way of measuring sound pressure levels. Many are available with built-in filters that allow the measurement to be displayed on the “A”, “B”, or “C” weighing scales. As with any sensitive piece of measuring equipment, calibration to assure measurement accuracy is vital. Given this, specialized sound calibrators are also available for use with the aforementioned Decibel Meters to assure result accuracy.

Sounds from a Gearbox

From the perspective of gearboxes (or gearmotors), operational sounds are generated through a variety of ways. The mesh of the gears, the rotation of the bearings, the splash of the lubricant, the operation of oil pumps, and the interaction of the gearbox itself within the machine structure – just to name a few
– all contribute to the normal overall sound generated by a gearbox during its operation.

In considering only the gear components, the tooth finish of the gearing itself contributes to the sound that is generated during operation. As an example, helical gearing that has been hobbed only would tend to be “louder” than a comparably sized helical gearset that has had a, post-hobbing, tooth finishing operation conducted on it. In this regard, shaving or grinding are finishing operations performed on the gear teeth to minimize, or eliminate altogether, the rough tooth surface finish that the hobbing operation often generates. It is important to note that, in terms of tooth finish, the rotation speed of the gearset also plays a significant roll in the sound that is developed. Very little difference, for example, would be noted between a hobbed only gearset that is rotating at 30 RPM verses a ground finished gearset of the same size also rotating at 30 RPM. Conversely, if the rotational speed of the gearset were to increase, one would note a marked increase in sound from the unfinished set in comparison to the finished one.

The quality to which the gearset is manufactured also influences the sound that it develops during operation. For clarification, the quality of a gear is often based on certain tooth characteristics such as tooth profile, tooth lead and tooth index. The following picture details these individual parameters as they relate to a gear:



Various organizations (i.e.: AGMA, DIN, JIS) have established quality rating standards based on tolerances associated with each of these parameters. Given these and their influence on how gears in mesh interact with each other, it is reasonable to say that, all else being equal, a gear set manufactured to a lower quality rating would likely generate more sound than a comparably sized gear manufactured to a higher quality rating.

Design choices to minimize operational sound are not limited to those aspects discussed thus far. There are other factors that a designer can consider that would serve to actively lessen sound. Incorporation of these sound-reducing options, however, may yield unfavorable consequences in other areas of the design. Ultimately it is up to the gear designer to clearly understand and prioritize his/her design intent. A firm understanding of the intent will allow the designer to balance the design variables accordingly such that all aspects are being achieved in ways that are both physically and financially viable.

Considering the gearbox as a whole: certain noises could also emanate from it that may provide an indicator of an undesirable situation. As an example, nicks or dings on the teeth of the gear(s) could easily yield a constant “clicking” sound as the face of the offending tooth (or teeth) come into contact with the face of the mating gear. Typically, gearbox manufacturers “run-test” a product after it has been assembled but prior to its shipment. The purpose of this run test is to ensure that the unit is operating normally. Sumitomo Drive Technologies, for example, conducts a comprehensive battery of tests on each assembled gear unit prior to its leaving the factory. Performance data (which includes sound) are measured, evaluated, and compared against nominal values to ensure that the product is operating within established limits.

How to Measure

While the theory of sound discussed so far has been informative and perhaps even interesting, the question remains as to how all of this information can be applied to real-world situations. As noted previously, noise can be a very subjective thing. To call a gearbox manufacturer to say that a gearbox is “noisy” may be a frustrating experience for the user if he/she cannot quantify their claim of noise more clearly.

Fortunately, we have defined the governing mathematical formula for sound pressure. This formula, combined with some applied mathematical operations, provides us with a means to more clearly define the sound that an installed gearbox is generating in application. What is described as follows is a method of subtracting an ambient or background noise from a total measured value thereby allowing one to determine the sound pressure level from a particular source.

To begin, let $L_{P,BACK}$ and $L_{P,SOURCE}$ represent the sound pressure levels of the background and source respectively. Then,

$$L_{P,BACK} = 20\log\left(\frac{p_{BACK}}{p_0}\right),$$

$$L_{P,SOURCE} = 20\log\left(\frac{p_{SOURCE}}{p_0}\right)$$

and:

$L_{P,TOTAL}$ = the total measured sound pressure value.

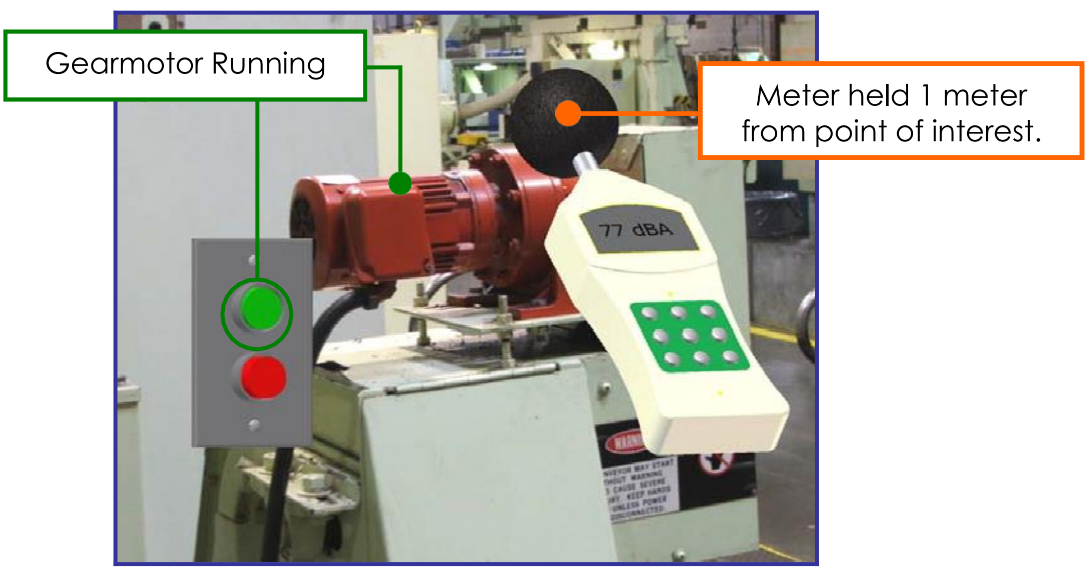
With these sound pressure levels defined, it can be mathematically proven that:

$$L_{P,SOURCE} = 10\log\left[10^{\left(\frac{L_{P,TOTAL}}{10}\right)} - 10^{\left(\frac{L_{P,BACK}}{10}\right)}\right]$$

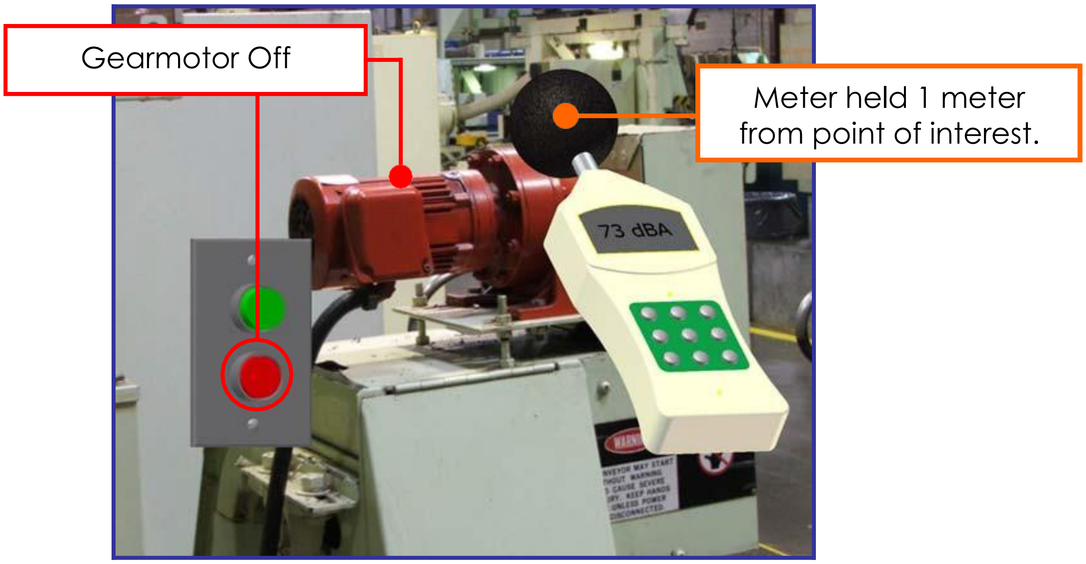
In essence, this equation provides the ability to calculate the sound from a source when the total sound ($L_{P,TOTAL}$) and background sound ($L_{P,BACK}$) are known through individual measurements.

To estimate the sound that is being generated by a gearbox, one first needs to measure the total sound in the area where the gearbox in question is located. About this, two points need to be made – first: the gearbox should be running while this measurement is being taken and second: typically, the meter should be held at a distance of 3 feet (1 meter) from the unit of concern. Once this measured value ($L_{p,TOTAL}$) is noted, turn the gearbox in question off and again measure the sound level in the same area where the first measurement ($L_{p,TOTAL}$) was obtained. This second measured value is $L_{p,\ BACK}$. To calculate the sound that the gearbox is generating in operation ($L_{p,\ SOURCE}$), simply insert the measured values into the defined equation to obtain the result.

As an example, say that there exists an interest in determining the sound that a gearbox is making while running in an application. Let's further say that, using a handheld sound power level meter, it has been determined that the total measured sound is 77 dBA. This value is $L_{P,TOTAL}$ and it is measured around the area of the gearbox in question while this gearbox is operational.



Finally, let's measure the sound pressure level (in the same area as $L_{P,TOTAL}$ was measured) when the gearbox in question is off. This value is $L_{P,BACK}$ and, for the purposes of this example, let us say that the measured value is 73 dBA.



Inserting these values into the equation:

$$L_{P,SOURCE} = 10\log\left[10^{\left(\frac{L_{P,TOTAL}}{10}\right)} - 10^{\left(\frac{L_{P,BACK}}{10}\right)}\right] = 10\log\left[10^{\left(\frac{77}{10}\right)} - 10^{\left(\frac{73}{10}\right)}\right]$$

Thus, using a scientific calculator, it is determined that $L_{P,SOURCE}$ = 74.8 dBA.

Depending on the application and the set-up, it may be possible to distinguish between motor sound and gearbox sound using the same mathematical procedure previously detailed. To begin, one would first need to disconnect the gearbox from the driven machine. Once disconnected, and with the motor and gearbox operational, proceed measuring the sound being generated by the combination of the gearbox and motor - this value is $L_{p,TOTAL}$. Then disconnect the motor from the gearbox and again measure the sound being generated while the motor is running. Using the previously defined nomenclature, this value would be $L_{p,BACK}$ (which essentially is the sound generated by the motor itself). Inserting these measured values into their respective locations in the equation would result in a value ($L_{p,SOURCE}$) that would be the calculated sound being generated by the gearbox by itself. This calculated value can now be compared against the measured value obtained from the motor itself to isolate more clearly which source is influencing the overall sound that is being heard.

For new equipment installations, it is recommended that baseline sound measurements are obtained and noted for future reference. Subsequent measurements of sound could be then compared to this baseline value for evaluation purposes.

Conclusion

Clearly, situations do exist where one can readily identify that a problem exists with a gearbox based on the sound (or more appropriately "noise") that it is making during its operation. Conversely, other situations also exist where "normal sounding" and "abnormal sounding" are simply too ambiguous to be of any diagnostic value. By understanding what "sound" is and applying some of the fundamental techniques addressed in this paper, the means does exist to quantify more clearly the sound that a gearbox or gearmotor is generating. This calculated or measured value, by itself, may not solely be used as a diagnostic tool. It's knowledge, however, may provide significant clues to the OEM or gearbox manufacturer regarding the condition of the unit in question. In turn this may provide a starting point in root cause analysis and, ultimately, corrective action measures.

References

American Gear Manufacturers Association – AGMA 914-B04 Gear Sound Manual. 2004

American Gear Manufacturers Association – AGMA 6025-D98 Sound for Enclosed Helical, Herringbone and Spiral Bevel Gears. 1998

Basaraba, Bruce., Archer, James, IPT's Rotating Equipment Handbook, IPT Publishing and Training Ltd. 1995

Halliday, David., Resnick, Robert, Fundamentals of Physics. John Wiley & Sons. 1988