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Review Article

Low Frequency (LFN) Noise: Effects and Assessment

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Abstract

Low frequency (LFN) noise is a noise that contains most of its energy in the lower portion of the spectrum, bellow the frequency of 200 Hz. It is generated by vibrations of large machineries, such as large power transformers, electric generators, compressors, etc. Energy at those frequencies propagates to large distances with little attenuation, so distances act as a low frequency filters. As a consequence, wide band noise at the origin becomes LFN far away from the source. This type of noise is also difficult to control, since the attenuation of noise control materials is low. Also the diffraction of barriers is largely ineffective. As a consequence, control of LFN requires sophisticated and expensive measures.

LFN is not considered hazardous, since it does not affect the hearing organ. However, it tends to be highly annoying, having also effects such as sleep deprivation, speech interference and others.

There is not, at the present, a uniformly accepted method for LFN assessment as well there are no set limits for acceptable noise levels. The most used method is still the A-C, although there are objections to it. This paper reviews the nature, effects and measurement status of the LFN.

Keywords: Noise; Annoyance; LFN; Noise Hazard; A-C Method

Summary

Noise is generally classified as Low frequency (LFN) when its energy is concentrated in the lower portion of the spectrum, below 200 Hz. It use to be the results of the vibration of large machines or parts of, such as electric generators turbines, large compressors, large trucks, etc. Although not hazardous, LFN tends to affects adversely exposed populations causing effects such as annoyance, sleep deprivation, speech interference, etc. There are not uniform accepted method for their measurement and assessment, the method A-C been the most commonly used at the present. This paper reviews the nature, effects and measurement status of the LFN.

Introduction

There is a large variety of noises, generated by different vibrating bodies or parts of them. This variety applies to their temporary characteristics so they sound continuous, intermittent or impulsive. Another characteristic applies to their spectral contents that make their pitch to be low, medium of high.

It is a well known fact that, depending of the sound level, human hearing is limited between 20 Hz and 20 KHz. Many animals perceive noises higher than 20 KHz, known as ultrasound. Most popular among them are bats and dogs. Elephants, on the other hand perceive easily noises with frequencies well below 20 Hz, known as infrasound.

Most noises found in every-day life are of broad band nature. Their energies are spread across the spectrum. The techniques of how to perform their measurement are well documented with relatively easy to use standards and regulations on how to do it.

Although they are found relatively often and tend to be annoying, they are difficult to assess and there are at the present no universally accepted techniques for their measurement (mainly what to measure and how). There are also no maximum acceptable limits for low frequency noise.

There are, however, situations, where most of the energy is concentrated in the lower end of the audible spectrum, mainly in the 20 Hz to 200 Hz region of the spectrum. They are the so called low frequency noises. Although their measurement is similar, the assessment presents problems, not yet solved. The reason for it is that there is not sufficient research done to determine what characteristics of the LF is the one that affects the most the recipients and for how much [1]. That is the reason for the existence of different methods no one adopted uniformly across the scientific world and, consequently, the regulators.

The points of entry for the sound energy into the human body are the ears. However, the effects from that energy are widespread, affecting different parts of the body in different ways going from raising the heart rate to raising the hearing level. Among the noise classifications, probably the most common is the division into hazardous and non-hazardous (annoying) noises. It is based on how they affect the human body: whether there is or no damage to the ear or parts of the hearing organs.

Probably, the most studied hazardous noises are those that affect directly our hearing causing the so called Noise Induced Permanent Threshold Shift (NIPTS). Presently, most standards and regulations agree that this happens for people exposed for 40 years, 8 hrs a day at levels at, or exceeding 85 dBA.

Unfortunately, no such uniformity exists when dealing with non-hazardous noises, responsible for annoyance, speech interference, sleep disruption or other similar noise effects.

Historically, the first serious studies into the way we perceive noise, were performed in 1933, when Fletcher and Munson [2] developed a set of equal-loudness contours using pure tones. Those contours represented sounds perceived as being of equal loudness at different frequencies. They clearly showed that loudness is strongly dependent of the frequency of the tone as well as of their sound levels. Also, that sounds at low frequencies are perceived as less loud than those at medium and high frequencies.

Contours were later revised by 1956 Robinson and Dadson [3] and became the basis for an ISO Standard.

The first instrument for noise measurement to be designed, the Sound Level Meters was intended to measure the loudness of a sound. In trying to introduce a simplification to the to the equal-loudness contours it contained three filters, denominated A, B and C. The first, A, was intended for measuring sound levels lower than 40 dB. C was intended for those higher than 70 dB, and B for all of those in between.

Studies performed later, found high correlation between hearing loss and results from workplace noise measurements performed using the A filter [5]. This is how the use of the filter A became universal for assessment of workplace noise and is still. Every Sound Level Meter (SML) today has the facility to measure noise in dBA.

Other studies found correlation between dBA and annoyance for other than hazardous noises (although the correlation is much weaker) increasing its use even further.

Presently, with the use of NRR [6] for the measurement of the attenuation provided by hearing protectors, the C-weighting (dBC) also became into widespread use and is incorporated into all SLMs [4]. Only the B curve has no use presently, up to the point that many SLMs do not have it at all. That does not excludes the possibility that a future break-through could not bring it back in circulation.

Hazardous noise

Noise is considered hazardous when it affects the ear, causing hearing loss. As a stress agent, it is known to cause other effects such as annoyance, sleep interference, speech masking, etc. There can also be effects on other systems such as the nervous system or the cardio-vascular system. However, those effects are considered as non-auditory and the noise causing them as non-hazardous.

As a result of well documented laboratory and epidemiological studies, there is an almost universal consensus that noise exposures in excess of 85 dBA (8hs/day, 5 days/w, 40 years) may cause hearing loss [5].

The determination if a noise y hazardous is done in two steps: first noise level is measured in dBA (using the filter A). Then, the result is compared to the above mentioned limit of 85 dBA. If the limit is exceeded, then the noise is qualified as hazardous.

[1] As a mater of fact, what is measured is the noise exposure, that is the integral of the noise levels the person is exposed during the workday.

What is not often mentioned is that this criterion applies to broadband noises, i.e. noises where the energy is spread uniformly along the audible spectrum. With few exceptions, the spectrum of most industrial noises exhibit broadband characteristics.

Non-hazardous noises

As mentioned above, noise that not affects adversely the human hearing is considered non-hazardous. That does not mean that it does not affect people. As a matter of fact, there are multiple effects, such as annoyance, sleep interference, speech interference task performance, etc.

Those effects are highly individual, affecting more some individuals than others. This is the reason why there are no uniform criteria for maximum acceptable limits of noise. There are guidelines, bylaws and local regulations that vary among countries and among local authorities.

A literature analysis relative to noise exposures that can disrupt sleep, communication, task performance, and productivity was prepared for the World Health Organization by concludes that noise measures based only on energy summation are inadequate for the characterization of most noise environments, particularly when health assessment and prediction are concerned, and durations of the measurements depend upon the activities involved. One must measure the maximum values of noise fluctuations, preferably combined with a measure of the number of noise events, and assess whether the noise contains a large proportion of low-frequency components [6].

Problems with measuring and assessing LFN [7]

To start with, there is no definition on what low frequency noise is. The term applies generally to noise with most of the energy concentrated below 200 Hz.

LFN does not affect hearing in general, but it can be quite annoying. Because of its physical characteristics, it does not decay easily with distance and travels distances without attenuation.

Walls and sound barriers, natural or artificial, are mostly ineffective for LFN control because of the diffracted energy that goes over and around the obstacle. Transmission loss of materials, on the other hand, decays with frequency [8]. Therefore, low frequency noise penetrates easily through walls into enclosures and living places. To make matters even worse, because of the long wavelength comparable to the size of rooms and offices, low frequency noise can generate standing waves with clearly audible hot spots that are highly annoying and difficult to control.

The measurement of LFN presents a problem. The usage of the A-filter under-values the impact of low frequencies. For example, a sound of 100 Hz is attenuated by almost 20 dB, while a sound of 50 Hz is attenuated by as much as 30 dB. The net effect of this attenuation, is that a noise with large low frequencies content (such as the one from a large truck engine) shows a low reading on a sound level meter, even though an observer can perceive it as an impressive roar.

In view of this problem, several attempts have been made to improve the assessment of LFN. The objective has been to obtain a relatively easy way to measure the noise so that the measurement correlates with the subjective feeling experienced by those exposed to the noise.

Probably the most popular method to come along is the C-A method. It is relatively easy to perform using a conventional sound level meter, since it simply requires to be measured in dBA and dBC.

Basically, it requires the following steps [9]:

- Noise is measured in dBA and dBC
- If the difference between both readings is larger than 10 dB, noise is characterized as LFN. (A large difference between both readings indicates that the noise has a large low-frequency content).
- If the noise is found to be LFN, a penalty, generally of 10 dB is applied to the measured dBA.

As an example, in the case of a a jurisdiction with a noise limit of 50 dBA, if the measured noise level is 45 dBA is measured it would be that considered acceptable. However, if there is a difference dBC-dBA larger than 15 dB, then the 10 dB penalty will be applied, and the assessed noise level will be 60 dBA. This would exceed the limit of 50 dBA and the noise will be considered inacceptable.

It would appear that this procedure is easy to apply and to obtain results also easy to understand and to apply. However, to be scientifically sound, there is a need to:

- Establishing the baseline limit (50 dBA in the above example). a) A baseline sound level, in dBA (50 dBA in the above example)

- Determine the difference dBC-dBA that classify the noise as a LFN (15 dB in the example) and
- Determine the penalty to be applied to the measured noise in dBA (10 dB). This penalty can be a fixed number, or can be proportional to the dBC-dBA difference.

To determine the values of those parameters, there is a need for psycho-acoustic studies to be performed over large samples of populations to be significant.

A proposal to replace the measurement in dBA by an improved dBC-dBA descriptor has been made recently [10]. It consists in averaging the dBA filtered sound levels of the 1/3rd octave bands between 16 Hz and 200 Hz and qualifying the noise as LFN when the C-A difference is equal or larger than 15 dB. This proposal requires frequency analysis with the claimed advantage of classifying as noisy situations that otherwise will not be recognized as such.

However, on top of the added complexity required in this new measurement technique, there is still the need for defining and justifying the three parameters mentioned above: baseline, definition of LFN and penalty.

Conclusions

This paper focuses on annoyance from non-hazardous, low-frequency noise and the difficulties in its assessment. The use of dBA is definitely not acceptable, unless different limits are set. The dBC-dBA method has been developed without defining and justifying the critical parameters mentioned above to provide support for any penalties applied to the measured noise levels.

LFN is definitely a highly annoying phenomenon that affects a significant portion of the population. Because it is of non-hazardous nature and because of the highly variant individual responses, (that make its study difficult) there is lack of knowledge, needed to find answers to the questions mentioned above.

There is a need for psycho-acoustic researches to be conducted to define and justify these parameters. In particular:

- Laboratory studies assessing annoyance from noise with different low- frequency content, both artificial and real-life (occupational, windmills, transit) and
- Surveys in real-life situations including measurements and questionnaires.

There is no point in getting more detailed data of the noise unless there are no limits set for those data.

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