INFERNO

ESTIMATION OF HEARING LOSS RISK

Summary made by Lars Kjellström

Royal Institute of Technology, Stockholm
MWL Dept. of Technical acoustics

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Conclusion

On the behalf of MultiSound Technology the siren system Inferno has been examined with respect to risks of hearing loss. The system generates a very strong and irritating sound in the frequency area around 3 kHz.

Since hearing loss is built up successively, a few exposures to noise are hardly any greater danger. If the sound pressure level is very high, more than 130 dB(A), immediate damages might occur. Inferno's sound pressure level has been measured to 125 dB(A) on 1 meter's distance. In order to estimate repeated exposures during a longer time, different norms are used. These norms are meant to be used in order to decide the risk for noise-induced hearing loss in work places and builds on daily noise exposure during an entire work life. Since burglars' working hours are hard to define these norms are hard to use in the Inferno case. An exception is ISO* 1999:1990 where the assumption of exposure can be more adaptable. If you estimate the noise exposure to 125 dB(A) for 1 minute per day during a year's time, the risk for hearing loss is 13%. This risk level is generally the one used when determining the limit for non damaging noise-induced hearing loss. Under the above mentioned exposure assumptions, Inferno is to be looked upon as harmless.

Research shows that a long period of silence between the noise exposures reduces the damage risk. Intermittent and short duration noise, 3-4 minutes, is also preferable. Both these conditions are acceptable for Inferno.

* International Organization of Standardization

Introduction

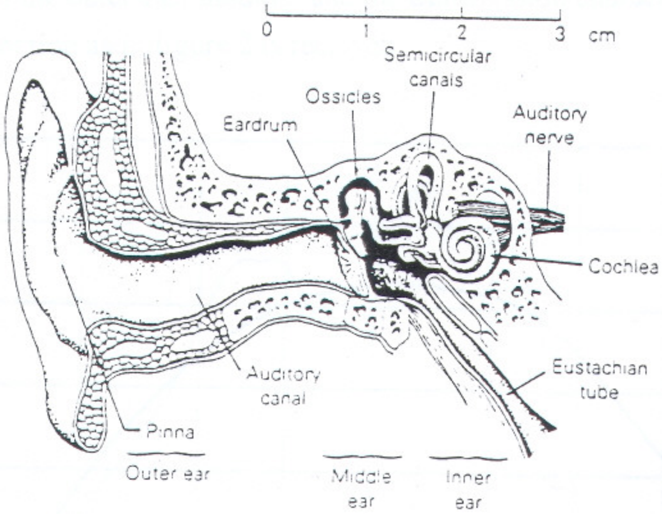
Inferno is a system of sirens intended to be a supplement to already existing alarms. It produces a very strong and irritating noise in the frequency range round 3 kHz[1]. The system consists of four separate signal channels which each generates a square wave. By shifting the four frequencies a most annoying sound is produced, which can be compared to untuned musical instruments.

This summary is aimed to judge if there is a risk for hearing losses. The class of risk is of course thieves but also contractors and service personnel.

First a short description of the anatomy of the ear and hearing losses is given.

Anatomy and audiology

Anatomy



1. Anatomy of the ear. Source: D. Hall. Musical acoustics.

The ear consists of three different parts, outer-, middle- and inner ear. The outer ear includes the pinna and the auditory canal. The geometry of the pinna settles the sensitivity at

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[1] 1 kHz=1,000 Hz

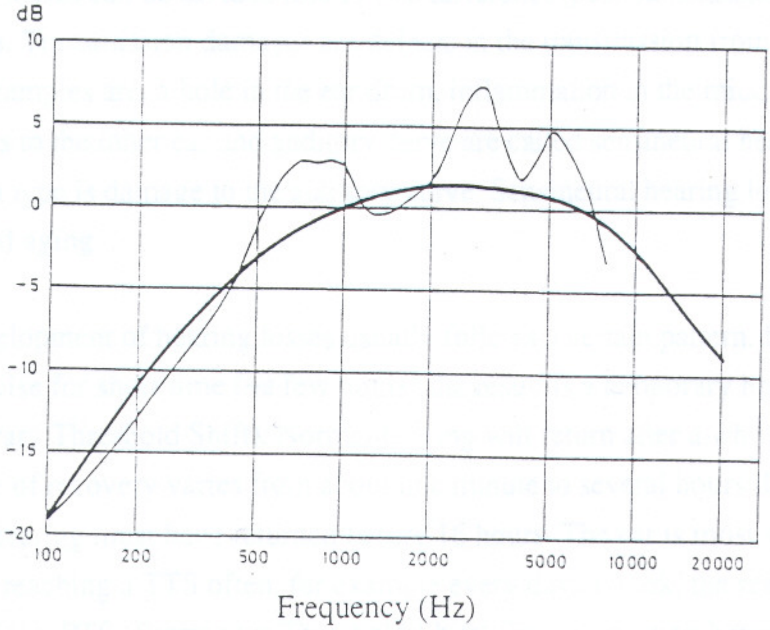
different directions and makes it possible to locate sound sources in altitude and forward or backward.

In the middle ear the eardrum and the ossicles work as a transformer between outer- and inner ear. Two small muscles in the middle ear make it possible to limit the motion of the ossicles. This reflex mechanism protects the middle ear from strong noises in the frequency range below 1,5 kHz.

The inner ear, which is filled with liquid, contains the semicircular canals and the cochlea. The cochlea is a coiled canal with a length of about 35 mm. In this canal the basilar membrane is located. When the basilar membrane is put into motion it activates the auditory nerve.

Limits of audibility

A young person with normal hearing is able to hear sound in the frequency range 20-20000 Hz. Aging affects the sensitivity for mainly high frequencies. At the age of 65 the over limit is about 12 kHz for women and 5 kHz for men. The sensitivity of the ear varies strongly with frequency. The length of the auditory canal causes a first resonance frequency at 3 kHz. Together with the outer ear, shoulder and the transmission characteristic of the middle ear a sensitivity function as in figure 2 is received.



2. Thin line: Sensitivity function of the ear. Thick line: A-weighing.
Source: Möller, Människan och bullret.

The figure shows that the ear is most sensitive in the frequency range 500-5000 Hz. This should be compared to the most important range for identifying speech which is 300-3000 Hz.

The difference between the quietest and strongest sound that can be detected is about 130 dB (rel. 20 μPa). Both the upper and the lower limits differ much, about ± 10 dB, from one person to another.

Weighing

Since the sensitivity of the ear varies with frequency, equipment for measuring sound pressure level often includes some type of weighing filter. Four different filters occur, A, B, C and D. The most common is the A-filter. A sound pressure level measured with an A-filter is termed with the unit dB(A) or dBA. The weighing function of the A-filter is given in figure 2.

Hearing losses

Hearing losses can be divided into to two different types, transmission- and sensineural damages. Transmission damages are defects in the transmission from outer ear to cochlea. Some examples are, a hole in the ear drum, inflammation in the middle ear or bad assicles. Damages to the inner ear and auditory nerve are called sensineural hearing loss. The most common type is damage to the auditory nerve. Sensineural hearing losses are mostly caused by noise and aging.

The development of hearing losses usually follows a certain pattern. If you are exposed to a heavy noise for short time (~a few hours) the result is a temporary hearing loss, TTS (Temporary Threshold Shift). Normal hearing will return after a while in a silent environment. The time of recovery varies from about one minute to several hours. By definition of TTS normal hearing must have returned before 16 hours. The ear is most sensitive to TTS at 4 kHz. If one is reaching a TTS often, for example every day at work, the result will be a lasting hearing loss, PTS (Permanent Threshold Shift). The connection between TTS and PTS is still subject of research. Due to ethic reasons it is also difficult to do experiments to confirm this connection.

An important type of noise is the impulse noise, which is characterized by very high sound pressure level and short duration (<1s). Examples of sound sources giving impulse noise are gunfire and hammer blows. Due to the short duration the brain will not be able to detect the real level of the noise. The ear itself is however fast enough to be affected. This means that impulse noise is more harmful than we believe. A special type of impulse noise damage is the acoustic trauma which is caused by one single very strong noise and gives an instant damage.

Estimation of hearing loss damage risk

Generally about regulations

Most of the existing regulations concern occupational noise. Hearing loss risk criteria is estimated from extensive audiologic researches of workers in noisy environments. To exclude natural reasons for hearing losses such as aging, the examined group is compared to a group of people who have not been exposed to occupational noise.

Common for all regulations is to try to estimate a sound pressure level that under certain assumptions is harmless. The assumptions made are about exposure time per day and the number of years of exposure. These parameters are usually set to 8 hours a day and 40 years, which is supposed to be a whole working life. While the sensitivity of the ear differs from one person to another, the question is how big fraction of a population should be taken care of. The spontaneous answer is of course that the whole population should be saved. Since some people are extremely sensitive, such demands would result in unrealistic exposure limits.

In table 3 some different organizations risk estimates are given. As definition of hearing loss an averaged PTS of 25 dB at the frequencies 500, 1,000 and 2,000 Hz are used. For example ISO thinks that 10 % of a population will have a PTS after 40 years of daily exposure of 85 dB(A).

Organization	Level dB(A) 8h, 40 years	Risk %
ISO	90	21
	85	10
	80	0
EPA	90	22
	85	12
	80	5
NIOSH	90	29
	85	15
	80	3

3. Risk for permanent hearing loss at different levels (Thresholdshift of 25 dB at 0.5, 1, 2 kHz). Source: Axelsson et al, Scientific basis of noiseinduced hearing loss.

To judge other day exposures than 8 hours, a term called equivalent sound pressure level is used. The assumption made is that the amount of hearing loss depends on the total noise energy received. In other words, a strong sound with short duration have the same effect as a weak sound with long duration. For example, if the exposure time is halved, the sound power can be doubled, which corresponds to an level increase of 3 dB. The increase of level permitted when exposure time is halved, is called coverting index or Q-factor.

A summary of some countries' limits (equivalent sound pressure level) and Q-factor is presented in table 4. Most countries have chosen the limit value 85 dB(A) and Q-factor 3 dB. One exception is the United States of America which have a limit value of 90 dB(A) and Q-factor 5 dB(A). This difference gives some peculiar results. An American ear stands 100 dB(A) for 2 hours while a Swedish ear stands that level for 15 minutes. This example only tells us that the knowledge about the ear's sensitivity is limited. Most scientists think that the values 85 dB(A) and 3 dB are more correct.

The knowledge about risks concerning impulse noise is yet limited. Many countries think that a limit value of 140 dB is reasonable.

Country	Limit value	Q-factor
Australia	85	3
Brazil	85	5
Canada	87	3
Finland	85	3
France	85	3
India	90	-
Israel	85	5
Italy	85	3
Japan	90	-
Netherlands	80	3
New Zealand	85	3
Norway	85	3
Spain	85	3
Sweden	85	3
United Kingdom	85	3
United States	90	5

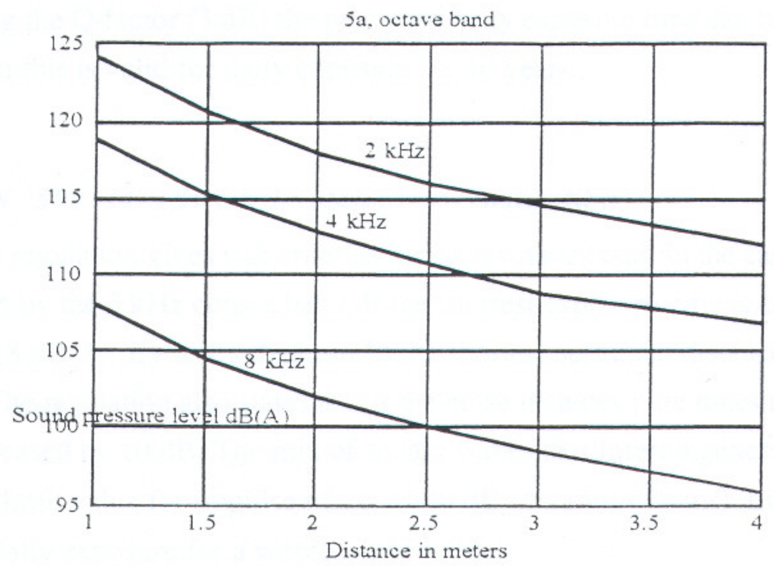
4. Limit values and Q-factors in different countries.
Source: Axelsson et al, Scientific basis of noise induced hearing loss.

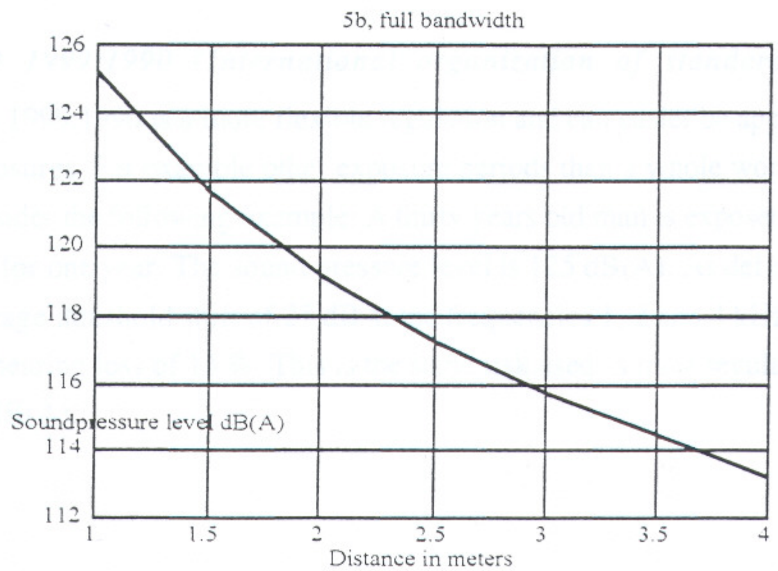
Regulations applied to Inferno

Following, three different regulations will be applied, AFS 1992:10, SEN 590111 and ISO 1999:1990. One problem is that most regulations are supposed to be applied to occupational noise with long time exposures. What working hours do a thief have? Can regulations be applied to very short exposure time? Probably they don't give a perfect answer, but can be used to give a rough estimate.

The diagrams below show the actual sound pressure levels, both for octave bands and full band width (630-16000 Hz). Measurements have been done for the distances 1 and 2.7 m. The other levels have been calculated with the assumption of direct sound field. This will be correct at the actual frequencies and if the absorption of the walls are relatively high. In rooms with acoustic stiff surfaces such as metal and glass, the dependence of distance may

not be so distinct. The calculations also assume that the distances to all loudspeakers are the same. If the distance to one of the loudspeakers is much shorter than to the others, this one will dominate. In that case the levels in the diagrams can be decreased by 2-3 dB.





5.a, b Sound pressure level as function of distance.

AFS 1992:10 (National Swedish board of occupational safety and health)

In this regulation the maximum level, independent of exposure time, is set to 115 dB(A). To not exceed this value the distance to the loudspeakers must be at least 3 m (see diagram 5b). By using the Q-factor (3 dB) the permitted daily exposure time can be calculated to 0,5 minutes. Then this is valid for daily exposure for 40 years.

SEN 590111 (Swedish standards institution)

This regulation gives risk criterias for each octave band. In the case of Inferno the limit will be fixed by the 2 kHz octave band. If the shortest exposure time is chosen (5 min.), the limit value is 118 dB(A). By using diagram 5a the shortest permitted distance to the loudspeakers will be 2 m. The regulation also states that if the noise includes pure tones the limit value should be decreased by 10 dB. The mix of square waves that Inferno generates do not give pure tones. The limit value for impulse noise is 140 dB (duration<20 ms). Like AFS, SEN 590111 is valid for daily exposure for a whole working life.

ISO 1999:1990 (International organization of standardization)

ISO 1999:1990 is a more flexible regulation and can easier be applied to different types of noise exposures. For example other exposure periods than a whole working life can be used. Let us consider the following example: A thirty years old man is exposed to Inferno one minute every day for one year. The sound pressure level is 125 dB(A). As definition of hearing loss an average threshold shift of 25 dB at the frequencies 1, 2 and 4 kHz is used. This results in a risk for hearing loss of 13 %. This is the same risk used in most regulations to state the limit value 85 dB(A).

Discussion and conclusion

The three regulations above give quite different results. Since it is not likely that thieves are exposed to Inferno every day for a whole working life, AFS 1992:10 and SEN 590111 overestimates the risk of hearing loss. ISO 1999:1990 can better describe the exposure conditions of Inferno and is therefore more reliable. Since hearing losses are gradually developed, single exposures are not dangerous as long as they do not exceed the level for acoustic trauma (instant damage). A reasonable value for this limit could be the limit value for impulse noise given in most regulations, 140 dB(C) peak[2].

There are qualities and conditions that are not taken care of in regulations. For example, long resting time between exposures (<16 h) decrease the risk for hearing loss. Compare this to a thief that do not commit a crime so often. Intermittent and short duration noise is also favorable. Some scientists also think that pure tones are more irritating but not more harmful than noise.

[2] Peak refers to measure equipment.

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