

Psychoacoustic model and perception threshold of low frequency sound in the presence of noise

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1. Introduction

Low frequency noise is radiated when heavy vehicles travel at high speed over highway bridges. Frequency of the noise thus generated often falls in the infrasound range i.e. below 20 Hz [1]. There has been an increase in the number of complaints arising from infrasound and low frequency noise in Japan [2]. Although there are reports of infrasonic effects that are potentially harmful or unpleasant to human subjects, research in this field is comparatively sparse. As the human auditory system is not efficient in detecting infrasound, the perception of infrasound differs from that of higher frequencies in some respects.

In order to describe the functioning of the human auditory system quantitatively, psychoacoustic models are in common use. Psychoacoustics deals with relations between perception of sound and physical properties of sound waves. Psychoacoustic models are developed based on the measured physical quantities of sound (i.e. sound pressure level) and their subjective feeling by human being (i.e. loudness). Zwicker's loudness model originally proposed and developed by E. Zwicker and later revised by Moore et al. is one of such psychoacoustic models that have been used in order to understand the hearing mechanism in auditory frequencies [3]. These models are limited only in audio frequency range. In this study, the revised Zwicker's model is modified and extended to infrasound frequencies also. The model differs from earlier models in assumed outer and middle ear transfer function, excitation level at threshold, range of representation of inner ear by filters and functions to compute those filters. The modified model is applied to determine perception threshold of low frequency sound in the presence of noise and the results are compared with experimental results.

2. The loudness model

Loudness is defined as the subjective judgment of intensity of a sound. Lines connecting points of equal loudness are called equal-loudness contour (ELC). Experimentally obtained ELC are shown in (Fig. 1). The lowest dash line in the fig. 1 is hearing threshold and first solid line is ELC of 20 phon. Five ELC at intervals from 20 to 100 phon at an interval of 20 Phon are shown in fig. 1. The data below 20 Hz are not standardized and are presented here as dotted line.

The Zwicker's loudness model is an empirical method to predict loudness from physical quantity of sound (i.e. sound pressure level). When sound is presented to human being, the stimulus sound is processed in auditory system and the subject responds to the stimulus with different level of loudness. The auditory system comprises of outer, middle and inner ear. Flow diagram of the auditory processing of the signal in ear can be represented by the flow diagram given in Fig. 2. Outer and middle ear is represented in the model by introduction of a fixed transfer function derived from inverted 100-phon ELC. This transfer function differs from those used earlier models in two aspects: no roll off is applied in low frequency region, and the range is extended below 20 Hz also. The roll-off is applied only in frequencies below 20 Hz. The stimulus after passing through outer and middle ear is processed in inner ear.

Inner ear in the model is represented by three stages: gain, frequency separation, and excitation of inner ear. Gain in inner ear is different depending upon the frequency of the stimulus. The sharp rise in hearing threshold compared to 100-phon loudness curve is assumed to be due to reduced gain from the inner ear (Fig. 1). The gain in the model is calculated from the difference in slope of 100-phon contour and hearing threshold. As change in slope between 100-phon contour and hearing threshold is not so

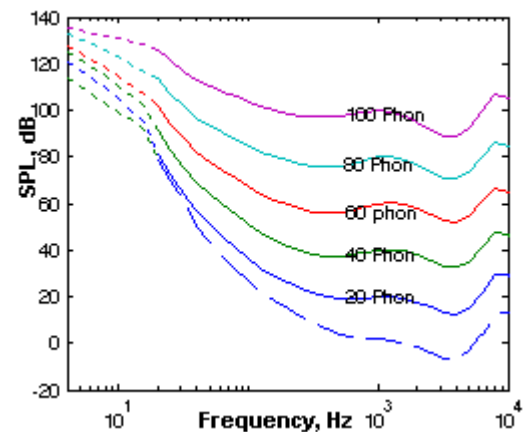


Fig. 1: Equal Loudness contour (20 – 100 Phon) and hearing threshold curve (dotted line). Data from 20 Hz and above are taken from ISO 226:1987. Data below 20 Hz are taken from Moller et al. (1984) [4].

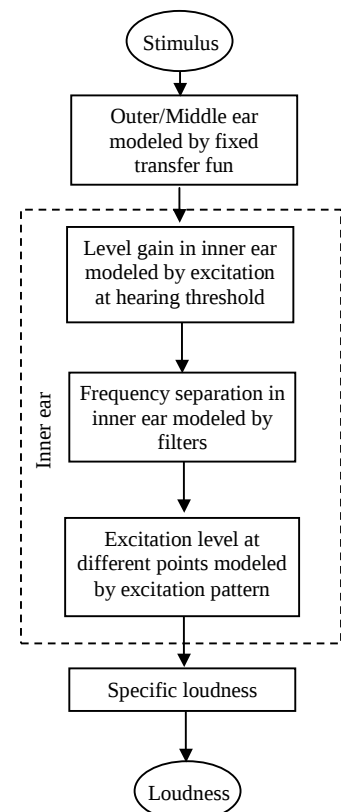


Fig. 2: Flow diagram of the model

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significant above 500 Hz, it is kept constant. Frequency separation in the inner ear is achieved by filters throughout the length of the inner ear. In earlier models, the filters were limited to frequency only above 50 Hz. As no discontinuity is observed in hearing threshold at 50 Hz, the range of filters is extended up to 20 Hz. As slope of the hearing threshold below 20 Hz decreases as seen in fig. 1, this assumption seems reasonable.

3. Application of the model

The model is used to predict threshold of the sound in the presence of noise components in higher frequencies. Excitation produced by the noise i.e. component of sound higher than the concerned frequency cause masking. Hence, higher sound pressure level is required to perceive the sound at that frequency. Excitation produced by the noise component is as shown in fig. 3. The area under excitation level vs. frequency gives level of masking. The sound pressure level required to produce same level of masking at concerned frequency is the threshold at that frequency.

4. Experimental observation

To understand the mechanism of perception of low frequency noise and infrasound in the presence of background noise, measurements were taken in an uncontrolled environment. The subjects were placed in a large room (6.5 x 3.75 x 5.3 m) in front of speakers and low frequency sound below 50 Hz was produced from speakers. No provisions were made to control the background noise and measurement showed that it was always exceeding the ISO hearing threshold above 50 Hz (Fig. 4 a & b). The subjects were first trained to concentrate on the concerned frequency i.e. below 50 Hz and ignore the noise. Thresholds were measured by asking subjects to adjust volume of the sound to make it just audible.

Measurement of one such case is shown in Fig. 4a. From the figure it can be seen that, with the increase in noise component i.e. sound above 20 Hz, the sound pressure level required to detect sound at 20 Hz increases. Results from similar measurements with 30 Hz as dominating frequency is shown in fig. 4b. Further measurements were taken by changing the dominating frequency and noise components.

5. Results

The threshold obtained from experiments and that calculated from the model are compared in the Table 1.

6. Conclusion

Difference in the results from experiments and the model is less than 2 dB in most of the cases and exceed 2 dB only in few cases. Considering the procedures adopted to measure threshold from experiments and the measurement conditions, this difference is not significant. Hence, it can be concluded that the modified model can be used to predict perception threshold of low frequency sound in the presence of noise.

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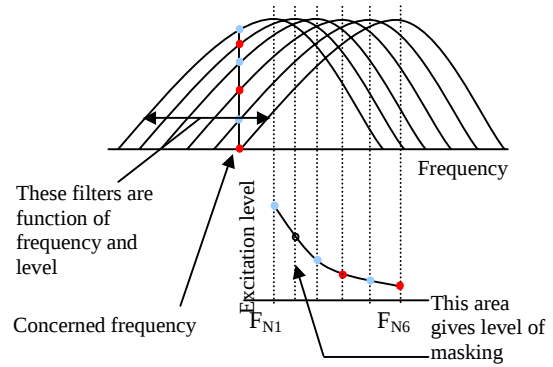


Fig. 3: Application of the model to calculate threshold in the presence of noise

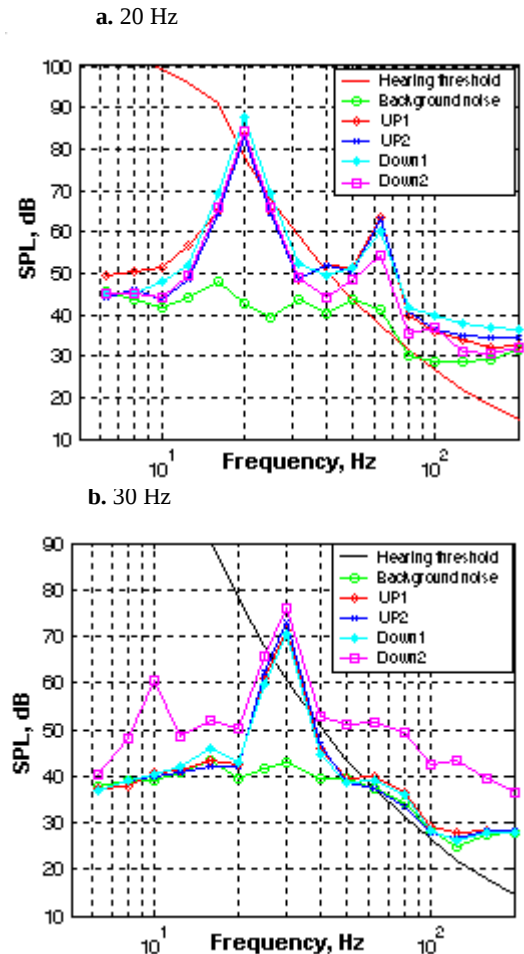


Fig. 4: 1/3 octave SPL of the sound measured at just noticeable level. a. 20 Hz b. 30 Hz. Solid line without mark is ISO hearing threshold curve. Measurements are taken four times – 2 times increasing the volume and 2 times decreasing the volume.

Table 1: Comparison of thresholds from experiment and calculated from model measured threshold

Fr (Hz)	Threshold (dB)		Diff. dB(±)	Fr (Hz)	Threshold, dB		Diff. dB(±)
	Measured	Calculated			Measured	Calculated	
20	83.2	84.7	1.5	40	69	67.5	1.5
	82.7	84.7	2		73	71.5	1.5
	87.6	84.7	2.9		71.5	71	0.5
	84.2	82.7	1.5		73	71.2	1.8
30	71.5	70.7	0.8	50	62.5	60.4	2.1
	73	70.3	2.7		61.5	61.6	0.1
	70.5	70.6	0.1		63.2	60.4	2.8
	76	77.4	1.4		63.8	61.7	2.1