INVESTIGATION OF THE EFFECT OF OBSTACLE PLACED NEAR THE HUMAN GLOTTIS ON THE RESULTANT SOUND PRESSURE

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ABSTRACT

Simulation of human vocal tract model is necessary to understand the effect of different conditions on speech generation. In natural calamities such as earthquakes person may swallow soil due to large amount of dust around. The effect of soil is investigated on the sound pressure in the human vocal tract. The generation of speech starts from the glottis, so the soil obstacle is positioned near it. The whole model is designed and analyzed using FEM. As the speech signal requires a bandwidth near about 4 kHz, the investigation carried out to obtained sound pressure in the human vocal tract from 100-5000 Hz sound signals.

KEYWORDS

Speech signals, human vocal tract, artificial models, glottis.

1. INTRODUCTION

Speech is the physical production of sounds. Words are created by sequence production of sound (consonants and vowels). Muscles, nerves and brain working together to plan and execute movements of the tongue, lips, palate, and jaw produce speech sound [1].

Speech model generated by human are given in Fig.1.The main articulators are the tongue, the jaw and the lips - as well as other important parts of the vocal tract (VT). For production of human sound, lungs facilitates storage of pressurized air and breathing muscles act as an energy source. The lungs are separated from the vocal tract by the vocal folds, which are also known as vocal chords. The vocal folds generate a signal, which is then filtered by the vocal tract and finally radiated to the surroundings via the mouth and/or nostrils [2-3].

Speech signals are the periodic signals with some fundamental frequencies. The speech signal can be processed by different possible ways, but depending on which speech sound wants to communicative. In voiced excitation, glottis open and closed periodically by air pressure and produced a periodic pulse which is in triangle–shape. In this type of excitation fundamental frequency lies in the range from 80Hz to 350Hz. Glottis is open and the air passes a narrow channel in the mouth or throat in unvoiced excitation. Unvoiced excitation results disturbances in the sound signal which generates noise. Position of the thinness determined the spectral shape of the noise signal. Closure inside throat or mouth will increase the air force in transient excitation.

DOI : 10.5121/ijnlc.2013.2106

Air pressure drops down instantaneously with suddenly opening the closure. The shape of the vocal shows the spectral shape of the speech signal [3-6].

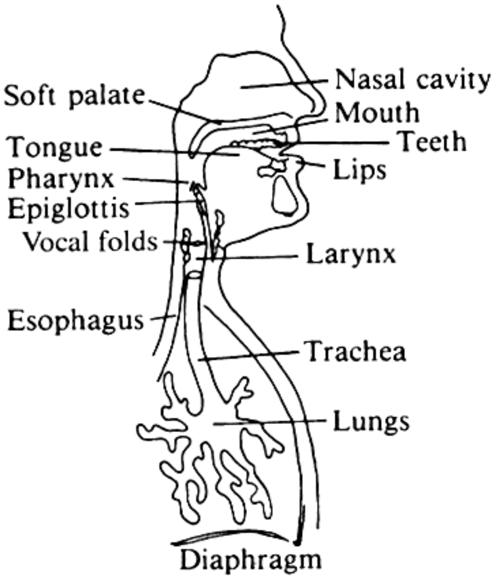


Figure.1 The human speech production organs.

1.1. Characteristics of Speech Signal

The various characteristics of speech signals such as bandwidth, fundamental frequency, peaks in the spectrum, and the envelope of power spectrum are discussed in this section

The bandwidth of the speech signal is greater than 4 kHz. Due to this, speech signal contains all the necessary information which is audible to human because there is a sufficient amount of energy in the spectrum for high and ultrasonic frequencies.

After passing the speech signal from glottis, the vocal tract changed the spectral properties and gives a characteristic spectral shape. If vocal tract is simplified into a straight pipe about length 17cm, then pipe showed resonant frequencies as given below

$$f_n = (2n-1)\times 500Hz, \text{ Where } n = 1, 2, 3, 4, 5 \text{ etc}$$

These frequencies are called formant frequencies. Frequency of the formants changes accordingly with the shape of the vocal tract.

The power spectrum produced by the glottis decreased with increase in frequency by -12dB per octave because with increase in frequency, envelope of power spectrum decreases. The emission characteristics of the lips give an idea about a high pass characteristic (+6 dB per octave). Thus this results in an overall decrease of -6dB per octave [7-9].

FEM based simulation of human vocal tract are done by many researchers [10-11]. In this research paper Fant's model of human vocal tract is adapted to simulate the human vocal tract using FEM, in order to investigate the effect of obstacle near the glottis on the sound pressure in human vocal tract.

2. ARTIFICIAL VOCAL TRACT MODELS

Many researchers have developed artificial models of human vocal tract[10-17]. Two artificial human vocal tract models developed by Umeda and Teranishi and Arai are discussed in this section. A simple human vocal tract device that simulated human speech acoustically was made by Umeda and Teranishi in 1966. In figure 2, moving (10-mm or 15-mm) the thick plastic strips, cross-sectional areas are changed when these strips are inserted closely from one side [12].

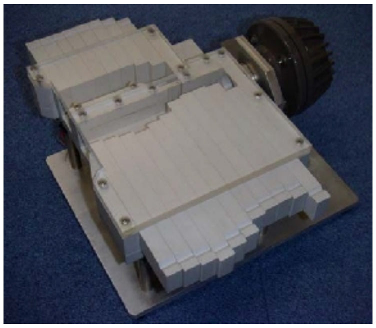


Figure.2 Artificial model of the human vocal tract by Umeda and Teranishi [12].

According to the configuration of the model various vowels and other sustained sounds are produced. Glottal signals are sent into glottis of the model and emitted from the mouth. Umeda and Teranishi investigated phonemic and vocal features of speech by using the model.

Arai replicated Chiba and Kajiyama's models of human vocal tract [13]. By using the physical models and electro larynx, vowels were produced [14]. This models help to understand acoustic theories, especially source filter theory and perturbation theory [15-16]. Figure 3 shows the two types of physical models of the human vocal tract: (a) the cylinder model and (b) the plate model. In cylinder model, the cavity forms around bottle-shape, based on the measurements by Chiba and Kajiyama [17]. In the plate model, every plate has a hole in the centre. When these plates are placed alongside then holes formed an acoustic tube and this changes the cross-sectional area in a step-wise manner. When a sound source is applied to either one end f these models, and then vowels are produced from the other plates.

(a) (b)

Figure.3 Physical model of the human vocal tract (a) cylinder model and (b) plate model [13].

3. METHODOLOGY

The human vocal tract is simulated using four tube model adapted from Fant's model of vocal tract as shown in Fig. 4. The length of three tubes is 15 cm. In this model, position of the centre of tube 3 relative to the glottis, the area (A3) of the tongue constraint, and ratio of the length (L1) over the area (A1) of the lip tube are analysed.

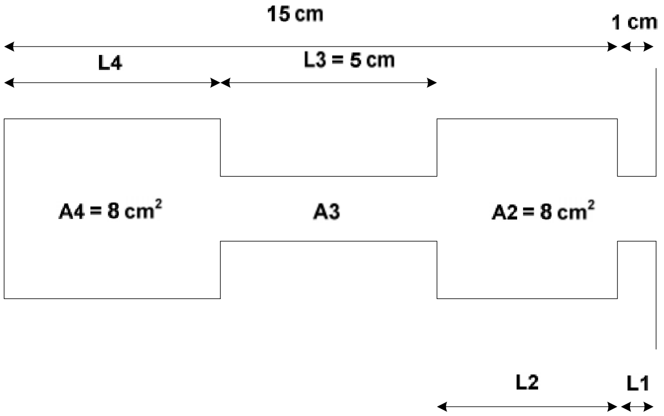
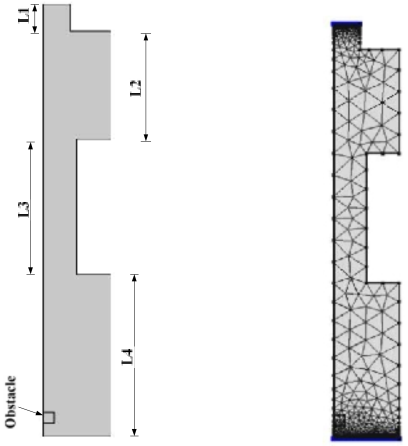


Figure.4 **F**our tube model of human vocal tract adapted from Fant's model [14].

The above discussed model was simulated in FEM based software. 2D axis symmetry model of the human vocal tract is designed shown in Fig. 5(a). The model was designed using four rectangular blocks in 2D geometry. The obstacle of length and width of 0.2 cm is placed at 0.5 cm from the glottis. The material used to construct these block are having density 1.25 kg/m^3 and speed of sound is 343 m/s. The material used for the obstacle is soil. The boundary of the wall is hard. A soft boundary is taken at the outlet of the block L1. A normal acceleration is applied at the block L4. The mesh analysis is carried out with maximum element size of 0.2 cm is taken shown in Fig. 5(b) The pressure acoustic study in frequency domain is carried out to investigate the effect of sound pressure with varying frequencies with obstacle placed at 0.5 cm from the glottis. The frequency domain analysis from 100 to 5000 Hz is carried out.

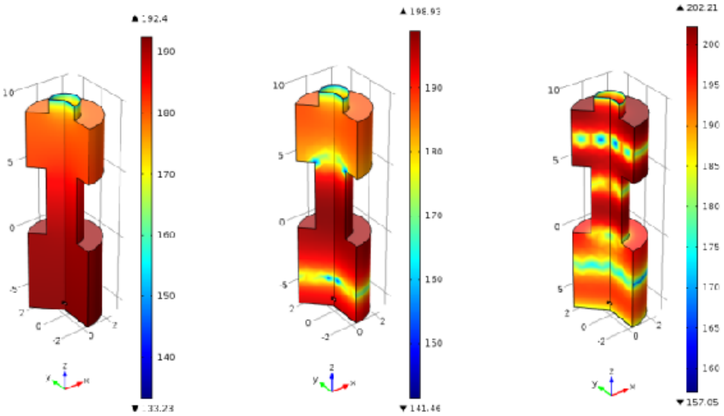


(a) (b)

Figure.5 (a) Designed model of human vocal tract with obstacle at 0.5 cm from the glottis and (b) Mesh formations with maximum element size 0.2 cm.

4. RESULTS AND DISCUSSION

The investigations were carried out using soil as obstacle materials at positions of 0.5 cm from the glottis having an length and width of 0.2 cm. 3D responses of sound pressure with different frequencies are obtained. Figure 7 shows the variation in the sound pressure with the application of frequency ranging from 100, 2100, and 4600 Hz to human vocal tract with the soil as obstacle positioned at 0.5 cm from the glottis.



(a) (b) (c)

Figure.7 Sound pressure variation in dB with the application of (a) 100 Hz, (b) 2100 Hz, and (c) 4600 Hz frequency in vocal tract.

The variation in the sound pressure with varying input frequencies is evident from the figures. The minimum and maximum statics and their difference of the sound pressure in dB are shown in Table 1. The minimum sound pressure value of 125 dB is obtained at 1600 Hz sound frequency. The maximum sound pressure of 214 dB is obtained at 2600 Hz. Difference between the maximum and minimum sound pressure is also calculated. The plot of the minimum sound pressure with change in the frequency is shown in Fig. 8. The least value of the sound pressure is seen at a frequency of 1600 Hz. The minimum sound pressure value initially increases and peaks are obtained at 1100, 2600, and 4600 Hz. Figure 9 shows the maximum sound pressure variation with frequencies. Two peak and dip points are obtained at frequencies 1100, 2600 Hz and 1600, 4100 Hz with values 201, 214 dB and 194 dB respectively. The statistics of the difference between maximum and minimum sound pressure is plotted in the Fig. 10.

Table 1.Statistics of maximum and minimum sound pressure with obstacle of length and width of 0.2 cm, positioned at 0.5 cm from glottis.

Frequency (Hz)	**Minimum (dB)**	**Maximum (dB)**	**Range (dB)**
100	133	192	59
600	146	199	53
1100	154	201	47
1600	125	194	69

2100	141	198	57
2600	156	214	58
3100	149	209	60
3600	146	200	54
4100	144	194	50
4600	157	202	45

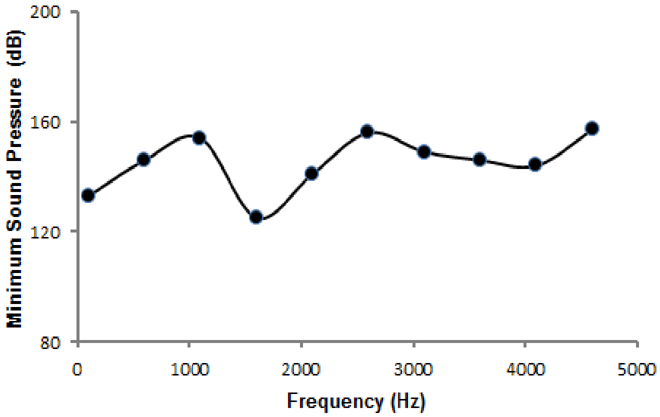


Figure.8 Minimum sound pressure noted at different sound frequency in human vocal tract with obstacle positioned near glottis.

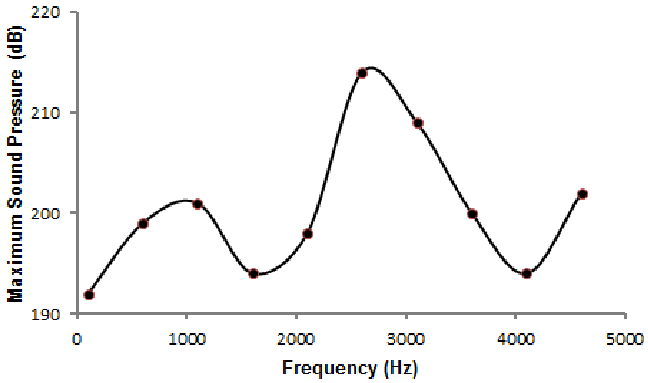


Figure.9 Maximum sound pressure noted at different sound frequency in human vocal tract with obstacle positioned near glottis.

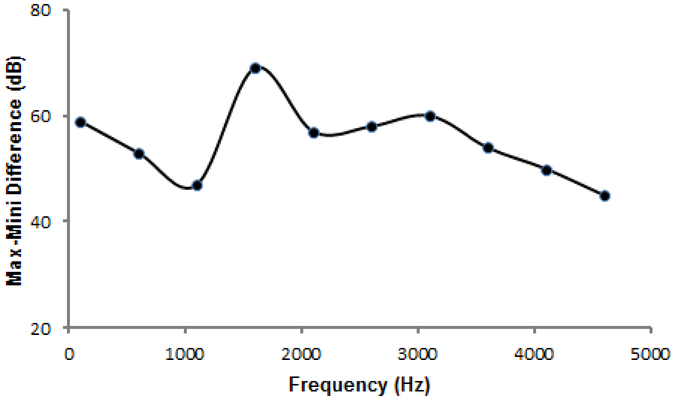


Figure.10 Max-Min difference of sound pressure noted at different sound frequency in human vocal tract with obstacle positioned near glottis.

5. CONCLUSIONS

The human vocal tract model is designed using FEM based platform. The investigations are carried out to determine the effect obstacle i.e. soil of length and width of 0.2 cm positioned at 0.5 cm from the glottis with variation of frequencies on sound pressure value in human vocal tract. At low frequency the sound pressure (100 Hz) variation is see the tube L1, at mid frequency (2100 Hz) the sound pressure variations is seen in tubes L1, L2, and L3, whereas for high frequency (4600 Hz) the sound pressure variations are seen in all the tubes. Soil obstacle in the glottis in the human vocal tract effects the proper propagation of the sound and cause variation in sound pressure in various parts of the human vocal tract.

ACKNOWLEDGEMENTS

This work was carried out at DSP Lab, Dept. of Physics & Electronic, University of Jammu, Jammu. The authors express their gratitude to Mr. Saleem Khan for help in conducting the experiment on the COMSOL.

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