The Dependence of Subjective Acoustic Indicators on Frequency and Position of the Sound Source

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The difference in the values of $C_{50}$ and $C_{80}$ indexes is slight at the front of the hall but it is considerable in the middle and at the back of the hall. As the distance between the orchestra and the listener is increased, the values of the $C_{80}$ index decrease from 0 dB in the front rows to −8 dB in the back rows. When the organ is playing, the change in the index values is not so significant: from −8 to −12 dB. The largest difference in $C_{50}$ and $C_{80}$ indexes is seen in the front rows, with large negative values. In the middle and back rows, the values of this difference become positive and almost stable. When the orchestra is playing, the variation of the low frequency index $C_{80}$ (3L) is slight in the front rows but they decrease sharply as the distance from the sound source S1 becomes larger. In case of organ music the values of the index are only negative and are almost not dependent on the listeners’ position. The character of change in the high frequency index $C_{80}$ (3H) is similar to that of the $C_{80}$ (3L).

When the orchestra is playing the values of the time centre of gravity are relatively low in the front rows but they increase as the distance from the sound source becomes larger. In case of organ music the largest values are obtained in the front rows and they increase along with the increasing distance from the sound source.

1. Introduction

It has been known that the acoustic properties of a concert hall are determined by its purpose, volume, proportions, acoustic characteristics and arrangement of sound-absorbing materials as well as the distance of the listener from the sound source. In typical concert or opera theatre halls, the sound source is always located on the stage or in the orchestra pit. In designing the acoustics of a concert hall, the position of the sound source during a symphonic music concert is taken as constant, though the distances separating individual instruments and their groups are quite large. The same can be said about orchestra pits in opera houses, where the musicians’ seats are arranged quite far apart. An opera soloist as a sound source is movable and variable in respect of both length and width of the stage within broad limits. The choir is usually arranged at the back of the stage. Thus in case of opera we have three different sound sources: the orchestra, the soloist and the choir.

Another situation is observed in old churches where symphonic and chamber music concerts involving soloists are held. The orchestra is usually arranged near the altar. Almost all churches have organs located in the balcony at the back of the church hall. Thus we have two very different locations of the sound source – at the back and at the front of the hall. Whatever the position of the listener, he or she will hear the sound of both the orchestra and the organ. This raises the question of whether the listener sitting in different places of the hall will perceive the quality of music sound in the same way.

The quality of music sound is determined by such objective acoustic indicators as the hall’s reverberation time, the structure of reflections, the diffusiveness of the sound field and the peculiarities of decay of the sound field energy. If these indicators had equal values at all places of the hall, one could assert that the quality of music sound is the same everywhere. However, no hall has ideal diffusive sound field. The decay of the sound field is not exponential in different places of the hall, just as the structure of reflections. As the orchestra plays, the latter will be quite different in the front and in the back rows. The same applies to organ music. The listener will perceive a distinctly different quality of music sound in case of organ and orchestra.

Raes and Sacerdote [1] feel necessary measurements at various source and microphone placements in the main nave. Moreover they take into consideration the influence of lateral naves behaving as coupled rooms. Lewers and. Anderson’s [2] article proves that acoustic field in large churches is strongly uniform. Their measurement results show qualitatively similar features as your results. M. Sankiewicz [3] writes detailed measurements revealed considerable differences among the values of the reverberation time, and of the rise time, evaluated for different places of the interior.

2. Geometrical Characteristics of the Hall under Investigation

The investigations were conducted in church has a very long and high hall. Its length to the altar is 55 m, width at the altar is 25.5 m, and height is 20.4 m. The volume of the hall is 27,000 m³.
The investigations were conducted in the hall without listeners. The sound source S1 was located not far from the altar, within the performers’ area, while the sound source S2 – in the balcony, at the distance of 2 m from the barrier. Thus S1 is on the floor plane and S2 is 7.8 m above the floor plane. Therefore, the distances from each measurement point to the sound sources S1 and S2 will be different.

The first point, i.e. within the performers’ zone, the distance from the sound source S1 is 3 m, from S2 – 41 m; at the fifth point, 7.5 and 31 m respectively.

A 16 mm caliber sound pistol was used as a sound source; it emits sufficient sound energy within the spectrum of frequencies being studied [4-8]. The sound source was raised 1.5 m above the floor.

The sound signal was reinforced through the diffuse microphone and applied to the analogue-to-digital converter and then stored in the computer memory. Afterwards the signal was analyzed by means of a special program developed by us by calculating the necessary objective and subjective acoustic indicators. The acoustic investigations were conducted in compliance with ISO 3382:1997 (E) [9].

3. The Dependence of the Subjective Acoustic Indicators of a Non-filtered Signal upon the Position of the Sound Source

Figure 1 shows the differences in the values of $C_{50}$ and $C_{80}$ depending on the location of the listener.

When both S1 and S2 are active, the largest difference in the values of $C_{50}$ is observed in the front rows. Here its negative values are equal to –11 and –12 dB. In the back rows, the difference is 2-4 dB, i.e. large positive values are observed. Similar changes are characteristic of $C_{80}$, too. In the front rows, the difference in values is –8-9 dB, while in the middle and the back rows it increases to 0-3 dB. Under the action of S1 and S2, larger differences in the back rows are obtained for $C_{50}$ than for $C_{80}$. This means that the listeners in the front rows will perceive the quality of music sound differently in case of organ and in case of orchestra music. When the orchestra is playing, strong direct sound is perceived in the front rows, which influences considerably both $C_{50}$ and $C_{80}$, whereas in case of organ music the influence of direct sound is insignificant.

Direct sound and first, second etc. reflections from different plane reach the listener first. The early sound energy is very important for the subjective perception of music sound. Fig. 2 shows changes in the direct sound index $C_2$ and the indexes $C_5$, $C_{10}$, $C_{20}$, and $C_{40}$ in various places of the hall when the sound source S1 is active. The Figures 2, 5, 10, 20, 40 mean the values of the early energy from 0 to 2, 5, 10, 20 and 40 ms.

The length of the direct sound index is taken as 0-2 ms [6]. Within the orchestra zone, the ratio between the direct sound energy and the remaining impulse energy is equal to –2.8 dB. Consequently, in this zone the energy whose length is 2 ms is less energetic than the remaining impulse energy by 2.5-3 dB only. This shows the scope of influence of direct sound in this zone. However, as the distance from the sound source S1 increases, the ratio becomes smaller, down to –18.9 dB. The same character of change is also seen when the early energy is taken from 0 to 5, 10, 20 and 40 ms. It is interesting to note that at the front rows the energy balance is observed only with the early energy taken as 40 ms. This is a very small value for a hall with such a long reverberation time. But the ratio decreases sharply with the distance from the sound source and is −16 and −17 dB at the back rows.

Different results are obtained when the sound source is in S2 position, i.e. when the organ is playing. The results of investigations are presented in Figure 3.
When the organ is playing, i.e. when the sound source S2 is at the back of the hall, the values of the direct sound index $C_2$ in the front and middle rows of the hall are negative and large (from $-77$ to $-83$ dB). This is because direct sound in these rows is weak, while the reflections are quite intense. However, at the back of the hall the index increases markedly up to $-22-24$ dB and changes insignificantly. Taking the early energy in the range of values from 0 to 5, 10, 20 and 40 ms, the character of change of the index is almost the same. It almost does not depend on the position of the listener; the larger the time interval of the early energy, the larger the values of the index.

4. The Dependence of Subjective Acoustic Indicators on Frequency and Position of the Sound Source

Any work of music is perceived by the listener as a great deal of sounds whose frequencies and energy varies within very broad limits. Figure 4 presents the average results of investigations of the $C_{80}(3)$ index at the frequencies of 500, 1000 and 2000 Hz.

The results are similar to those obtained for an unfiltered signal. When the orchestra is playing, i.e. where the sound source is in the position S1, positive values of the index (0.6-0.7 dB) are recorded in the performers’ area. As the distance from the sound source increases, $C_{80}(3)$ index decreases suddenly to the values from $-9.5$ to $-11$ dB in the middle and at the back of the hall.

When the organ is playing, i.e. with the sound source S2 active, the $C_{80}(3)$ index is only slightly dependent on the distance and its values are negative, varying from $-9.5$ to $-11$ dB. This means that, as the orchestra is playing, the high frequency energy prevails in the performers’ area; it decays significantly with the increase in the distance from S1. In case of organ music, this energy is low in all rows.

Figure 5 depicts the change in the low frequency index $C_{80}(3L)$ which was obtained by averaging out the low and medium octave frequencies of 125, 250 and 500 Hz.

When the orchestra is playing (sound source S1), the values of $C_{80}(3L)$ are quite stable in the front rows (around 0). As the distance from the sound source increases, these values are equal to $-10$ $-11$ dB at the back of the hall. When the organ is playing (sound source S2), the values of the index are only negative and are almost not dependent upon the position of the listener. This means that in case of orchestra the low frequencies are much more energetic in the performers’ zone compared to the middle and back rows of the hall. This does not apply to orchestra music: the low and medium frequencies are less energetic everywhere.

5. Conclusions

- The listeners’ perception of sounds of music will be qualitatively different in case of orchestra music (sound source S1) and organ music (sound source S2). The position of the sound sources influences strongly the listeners seated at the front of the hall,
whereas the listeners in the back rows are almost unaffected. The larger distance from the orchestra, the smaller the difference.

- As the distance between the orchestra and the listener is increased, the values of the $C_{80}$ index decrease from 0 dB in the front rows to –8 dB in the back rows. When the organ is playing, the change in the index values is not so significant: from –8 to –12 dB.
- The largest difference in $C_{50}$ and $C_{80}$ indexes is seen in the front rows, with large negative values. In the middle and back rows, the values of this difference become positive and almost stable.
- When the orchestra is playing, the variation of the low frequency index $C_{80}(3L)$ is slight in the front rows is slight but they decrease sharply as the distance from the sound source $S_1$ becomes larger. In case of organ music the values of the index are only negative and are almost not dependent on the listeners’ position.

References


