DEPENDENCE OF THE DIRECT SOUND ENERGY UPON THE DISTANCE TO THE SOUND SOURCE

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ABSTRACT

It has been established by investigations that the duration of direct sound is little dependent upon the distance to the sound source. It decreases from 0.4 ms near the source to 0.25 ms at the distance of 41 m from the source. The amplitude of direct sound decreases along with the increase in the distance to the sound source; the decrease is more marked within 11 m. At the distance of 41 m from the sound source, absolute energy of direct sound of an unfiltered signal is reduced by about 20 dB. Direct sound near the sound source is less energetic than reflections in the time interval from 0 to 50 ms by 18-20 dB. At the back of the hall, at the distance of 41 m from the sound source the difference amounts to 28 dB.

INTRODUCTION

Sound energy consisting of direct sound, early reflections and diffusive sound will reach the listener at any place of the hall. The quality of sound perceived by the listener will depend upon the spatial and time structure of the sound field in the hall.

Direct sound is very important for the perception of music because, reaching the listener first, it provides information about a work of music. As the distance from the sound source increases the object of hearing becomes more prolonged and diffusive.

Direct sound always prevails in the performers' zone, near the sound source. The early reflections arrive to the listener later: the wider and higher the hall, the later the arrival. As the distance from the sound source increases, direct sound becomes less energetic, while the early reflections reach the listener earlier as compared with the situation when the listener is close to the sound source. The energy of these reflections will differ at various places of the hall.

The ratio between direct sound and diffusive sound is considered to be one of the criteria of evaluation of a room's acoustics.

Direct sound was used by Ch.A. Shchirzeckij [1] for the studies of critical distance at which the direct sound energy is equal to the diffusive sound energy. He investigated the isotropy of sound field in five directions, measuring only the sound pressure in three octave bands. Direct sound was used for the critical distance studies by J. Mourjopoulos [2], J.Jetz [3], T. Gorne [4], and W. Reichardt [5] .

The purpose of this work is to investigate experimentally the change in the form, pressure and energy of direct sound in relation to the distance to the sound source.

1. SOUND FIELD CHARACTERISTICS

Density of energy is a good indicator of the sound field of a closed room. In a free space, far from the sound source, the energy of sound decreases in inverse proportion to distance and in direct proportion to the energy emitted. This regularity does not apply to closed space.

At any point of a closed space, the density of energy is characterised by density emitted by the sound source and density formed by sound waves reflecting from various planes. Let us assume that the sound source emits energy *P*. Then the density of direct sound at the point under consideration is equal to:

$$W_t = \frac{P_A \Omega \phi_t^2}{4\pi r^2 c_0} \quad (1)$$

where P_A – is the acoustic power of the source; Ω – is the ratio of the axial concentration of the source; φ_d – is the directivity ratio of the source; *r* – is the distance from the source to the point under consideration; c_0 is the sound velocity in the air.

The density of the direct sound energy may be expressed through the sound pressure. Their relationship is as follows:

$$W_t = \frac{p^2}{\rho_0 c_0^2} . \quad (2)$$

where p is the average square of the sound pressure; ρ_0 – is the air density.

Upon inserting (2) into (1) a direct sound pressure square is obtained:

$$\overline{P}_t^2 = \frac{P_A \Omega_t^2 \phi_t \rho_0 c_0}{4\pi r^2} \quad (3)$$

At the distance of 1 m from the source, the direct sound pressure square is expressed, based on the source axis, as follows:

$$\overline{P}_t^2 = \frac{P_A \Omega_t^2 \rho_0 c_0}{4\pi} \quad (4)$$

Direct sound will reach the listener first, followed by the first reflection. The density of its energy is equal to:

$$W_{at} = \frac{P_A \Omega_t^2 \phi_{at} \beta}{4\pi(r_1 + r_2)c_0^2} \quad (5)$$

where: ϕ_{at} – is the source directivity ratio between its acoustical axis and vector r_1; β – is the plane reflection ratio; r_1 is the distance from the source to the reflection plane; r2 is the distance from the reflection plane to the listener.

2. GEOMETRICAL CHARACTERISTICS OF THE HALL

The experiments were carried out in a church whose construction was started in 1287 and finished in 1426. Symphony, chamber and choir music concerts are held in it. The church has a very long, high and wide hall.

The length of the hall to the altar is 55 m. It has three naves: the middle nave is 12.5 m wide and the lateral ones are 6 m each. The overall width at the altar is 24.5 m, at the entrance – 25.5 m. The height of the middle nave is 20.4 m, while that of the lateral naves 19.4 m. There are two rows of 2×2 m columns, five columns each. The volume of the hall is 27,000 m³. There are 24 rows of wooden benches seating approx. 600 listeners. Venetian mosaic floor has been installed in the church. All the walls and ceilings are plastered. There is a balcony at the back of the hall, with the width varying from 5 to 8.5 m. There is an organ is the balcony but it is not in use. The layout and the longitudinal sections of the hall are presented in Fig. 1.

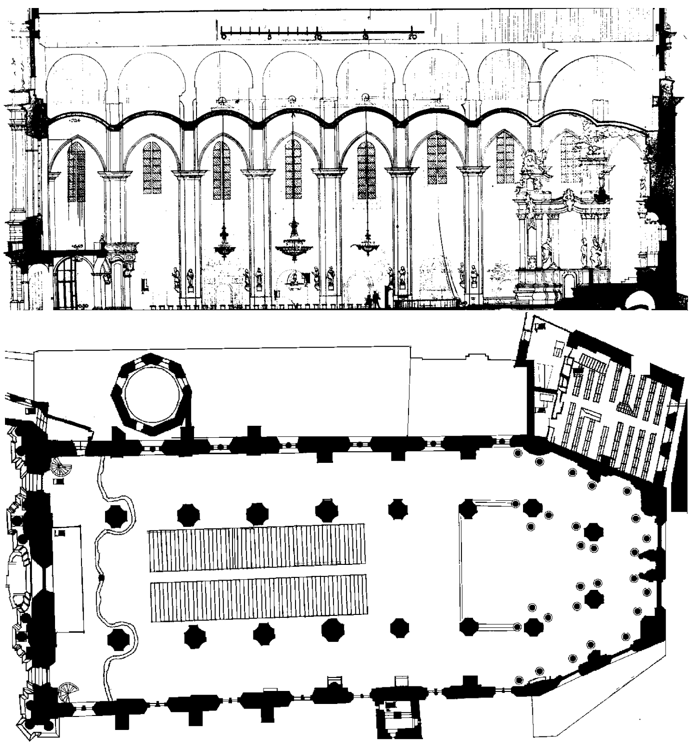

Fig. 1. Layout and longitudinal sections of the hall.

A pistol of calibre 9 was used for the experiments with the sound source. The source was arranged at the height of 1.5 m from the floor and at the distance of 1 m from the longitudinal axis of the hall. The measuring microphones were allocated along the hall's longitudinal axis. The largest distance from the sound source to the microphone is 41 m. The sound signal was fed from the diffusive microphone to the analogue-to-code converter, which converted the signal into the digital form. A special analytical program was developed for the acoustic analysis of signal.

3. RESULTS OF INVESTIGATIONS

Fig. 2 depicts the change in the pressure and form of direct sound of 1 ms in along with the distance to the sound source. Both positive and negative part of direct sound is depicted.

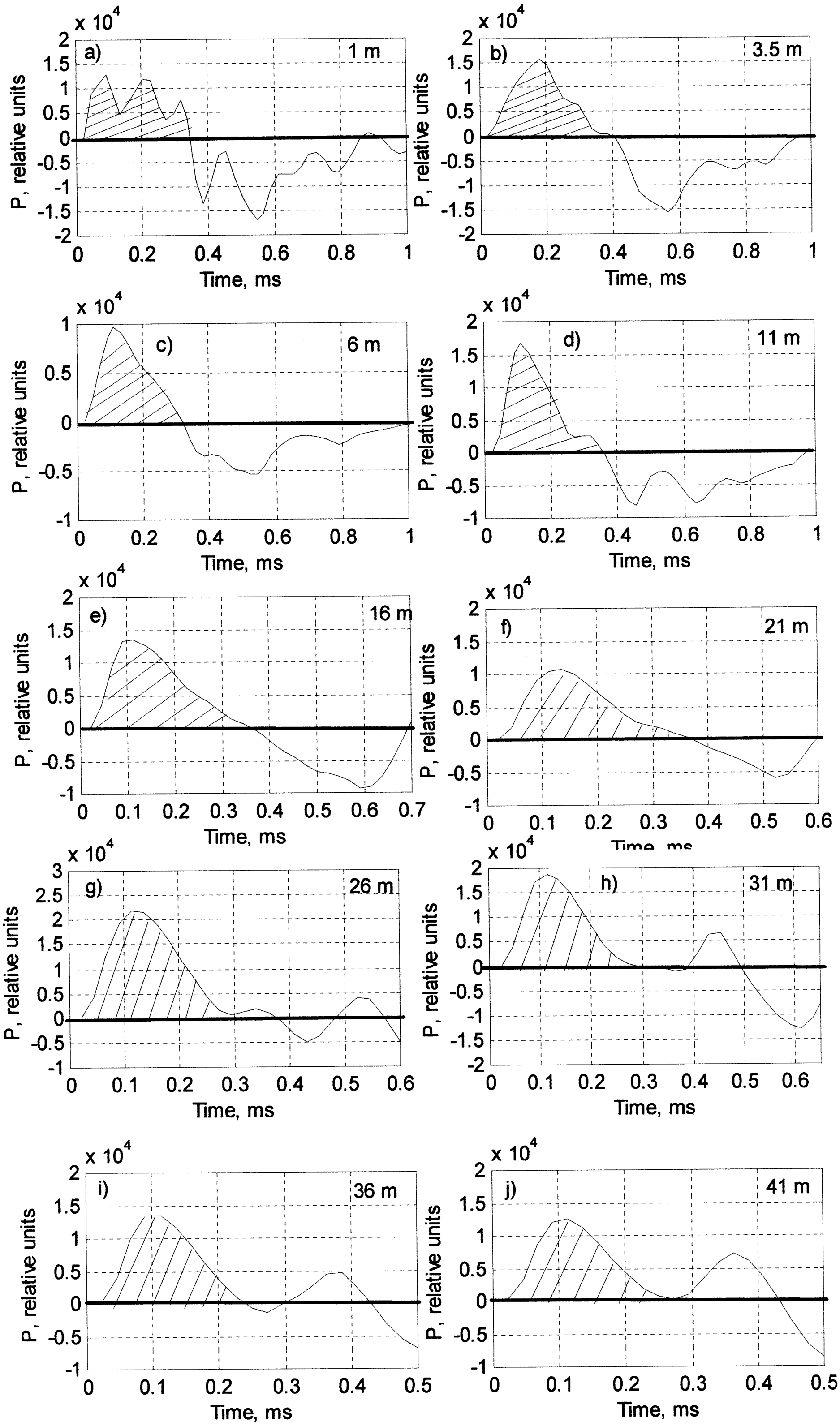

Fig. 2. Dependence of the amplitude and form of direct sound of an unfiltered signal upon the distance to the sound source. a), b), c), d), e), f), g), h), I), j) – distance from the microphone to the sound source is equal to 1, 3.5, 6, 11, 16, 21, 26, 31, 36 and 41 m respectively.

When the distance to the microphone is very short – 1 m, direct sound has no definite form. In this case the microphone is significantly affected by the shock sound wave, which weakens along with the increase in the distance. When the distance to the microphone is 1 and 3.5 m, the duration of direct sound is 0.38-0.4 ms. As the distance is increased to 21 m, the duration remains at approx. 0.38 ms. When the distance is 26 and 31 m, the duration of direct sound is 0.3 ms. When the distance increases up to 36 and 41 m, the duration of direct sound shortens to 0.23-0.25 m.

The amplitude of direct sound is dependent upon distance as well. The greatest decrease is observed within the distance of 11 m from the sound source, beyond which the decrease is not so marked though noticeable.

Fig. 3 shows the dependence of the absolute direct sound energy of unfiltered signal and of the first reflections' absolute energy upon the distance to the sound source.

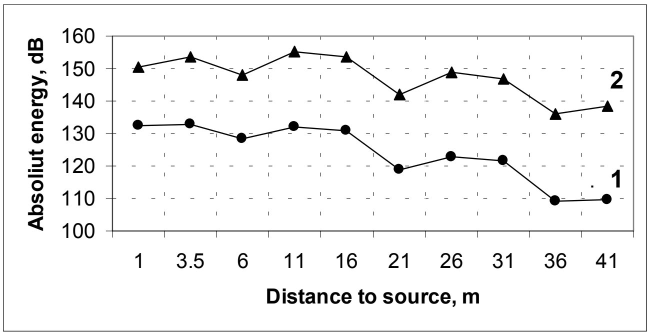

Fig. 3. Change in the absolute energy of direct sound of unfiltered signal and of the first reflections depending on the distance to the sound source and the length of pulse measured. 1 – only direct sound, from 0 to 0.4 ms; 2 – from 0 to 50 ms.

Within the distance of 16 m to the sound source, the absolute energy of direct sound varies insignificantly. Where the distance is increased to 21 m, a 10 dB decrease in the sound energy is observed. It remains almost on the same level when the distance to the sound source is 26 and 31 m. As the distance is increased to 36 and 41 m respectively, an additional 10 dB reduction is seen.

Curve 2 in Figure 3 characterises the energy of the early reflections in the time interval from 0 to 50 ms compared with the direct sound energy. At the front rows of the hall, there are no early reflections from the ceilings and lateral walls within the time interval up to 50 ms. There is only a reflection from the floor and the nearest column as well as diffracted reflections of the operator. Close to the source, direct sound is less energetic by 18-20 dB compared to the reflections' energy in the time interval from 0 to 50 ms. This is much given that there no intensive reflections in this interval. The quantity of the early reflections increases along with the distance from the sound source. Therefore, at the back of the hall and within the time interval from 0 to 50 ms, direct sound is less energetic than the reflection energy by 28 dB.

CONCLUSIONS

1. The duration of direct sound is little dependent upon the distance to the sound source. It decreases from 0.4 ms near the source to 0.25 ms at the point 41 m from the source.

2. The amplitude of direct sound decreases in inverse proportion to the distance to the sound source. This decrease is more marked within the distance up to 11 m.

3. At the point 41 m from the sound source, the absolute energy of direct sound of an unfiltered signal decreases by about 20 dB.

4. Near the sound source, direct sound is less energetic than the reflection energy by 18-20 dB within the time interval from 0 to 50 ms. At the end of the hall, at the distance of 41 m from the source, the difference grows to 28 dB.

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