The Late Reverberation Time as a New Criteria For the Evaluation of Hall Acoustics

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Abstract: It has been established by investigations that a resonant sound field is created in a small rectangular hall by the repetitive echoes between parallel walls and semi-upholstered chairs arranged in rows. Therefore, at the low frequencies, the reverberation times approximated according to the field decrease from -30 to -35, from -35 to -40 and from -40 to -45 dB are longer than the reverberation time of an empty hall. Such time should be called the late reverberation time.

OBJECTAND AND RESULTS OF THE INVESTIGATIONS

Measurements are necessary to assess the acoustics of newly constructed halls. ISO 3382:1997 requires that the reverberation time be established by approximating the sound field decrease from -5 to -35 dB. However, the decrease continues after -35 dB and is perceived by the listeners, therefore it must be assessed as well.

The experiment was carried out in a small rectangular hall which is 13.7 m by 10.7 m by 7.0 m. The parquet floor of the hall and the ceiling are horizontal. The planes of all walls and the ceiling are even and made of sound reflecting materials. The investigations were conducted in the empty hall, in the hall with 120 semi-upholstered chairs, and in the hall with 170 semi-upholstered chairs. The sound field was evoked by a sound pistol. The reverberation time was established by Schroeder's method [1].

Fig. 1 shows how the sound field of an unfiltered signal decreases in the empty hall and in the hall with 120 and 170 semi-upholstered chairs.

\[ E_{\text{max}}, (\text{dB}) \]

\[ \begin{array}{c}
\text{Time, (ms)} \\
\end{array} \]

![Graph](image)

FIGURE 1. The decrease of the sound energy of an unfiltered signal depending on time and filling of the hall: 1 - empty hall; 2 - hall with 120 semi-upholstered chairs; 3 - hall with 170 semi-upholstered chairs.

In the empty hall, the decrease of the unfiltered signal's sound field is nearly exponent throughout the period of decrease. When 120 chairs are arranged in the hall, the sound field decrease is almost exponent during the first 1500 ms only and then it slows down. When the number of chairs is increased to 170, this almost exponent decrease is observed on a shorter interval - approximately till 1000 ms, and then becomes still slower. The early field decrease is sudden and the late decrease is slow. In the interval from 0 to 500 ms, the field decreases by 18 dB, while in the interval from 2000 to 2500 ms - only by 8 dB. Thus, in a small rectangular hall, the character of the sound field decrease is changed considerably by chairs.

Two different periods may be distinguished in the field decrease: the early period and the late period. The early decrease is determined by the chair absorption, while the late is determined by the resonant sound field. The later is
produced by the repetitive echoes between the parallel walls and the rows of chairs. The resonances arise between the rows of chairs, while the repetitive echo supports the sounding of excited resonances at the low frequencies, due to which the decrease of the sound field slows down.

Fig. 2 depicts the values of the reverberation time when the sound field decrease is approximated in different level intervals.

**FIGURE 2.** The dependence of the late reverberation time on frequencies and the intervals of the sound field approximation levels. 1 - standard reverberation time of the empty hall when the decrease is approximated from -5 to 35 dB; 2 - same with 170 chairs; 3 - late reverberation time when the decrease is approximated from -30 to -35 dB; 4 - from -35 to -40 dB; 5 - from -40 to 45 dB.

The investigations show that the late sound field decrease by 5 dB takes place in the interval from 200 to 400 ms and will be perceived by the listeners. The late reverberation time occurs at the low frequencies in the 100-160 Hz interval. Its values are considerably larger than those of the standard reverberation time and much larger than the reverberation time of the empty hall. At 63-80 Hz, its values are very small because the dynamic range is too narrow at these frequencies.

**CONCLUSIONS**

1. If the air volume resonances arise in the hall, the decrease of the sound field after 30-35 dB is much slower than that in the initial interval of the decrease. For this reason the late reverberation originates, whose times are much longer than the standard reverberation time.
2. If the sound field decrease in the room is not exponent, the standard reverberation time obtained by approximating the decrease in the sound field energy from -5 to -35 dB cannot be the only guideline in correct characterisation of the sound field decrease in a closed room, i.e. the hall reverberation time.
3. The existence of the late reverberation time means that there is no diffusive sound field in the hall and that the hall has acoustic defects.

**REFERENCES**