DECAY OF NON-DIFFUSE SOUND FIELDS IN A ROOM

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Abstract. The paper presents the results of a study of a non-diffuse sound field decay in a room. In a laboratory experiment, a model of a room in the form of a rectangular parallelepiped with a size of 0.7 x 0.4 x 0.4 m is used. Two non-parallel walls are coated with sound absorbing material. Sound scattering elements can be placed on the third wall which is perpendicular to the absorbing ones, which allows to change the field diffusion degree. The sound field in such a room has a strong anisotropy, its energy decays according to the exponential-power law. Sound decay curves were measured at various positions of the sound source and microphone at frequencies of 4 kHz. The decay curves are compared, their dependence on the relative position of the sound source and microphone is analyzed.

1 Introduction

It is well known that the energy of a diffuse sound field in a room decays exponentially with time [1]. To ensure the diffusion of the field, it is necessary that the room has a sufficiently complex form, and sound absorption is evenly distributed all along its walls. In rooms of a simple form, for example, shaped as a rectangular parallelepiped, the sound decay occurs according to an exponential-power law, and if the room has at least one pair of parallel absolutely reflecting walls, then according to a power law [2,3].

Reverberation time is one of the main parameters used to evaluate sound quality in rooms [4]. Non-exponential sound decay leads to well-known problems with determining the reverberation time: the decay curve non-linearity (the logarithmic level of sound energy in the room versus time) leads to different reverberation times at different intervals of sound level drop, therefore its value substantially depends on the part of the measured decay curve. In limiting cases, the value of the reverberation time calculated from different parts of the same decay curve can differ several times [5]. In practice, sound decay laws other than exponential are found in different rooms [6,7].

On the other hand, creating conditions for the appearance of a non-diffuse field and, as a consequence, non-exponential decay is proposed to be used as an acoustic design method for

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concert halls [8]. Non-diffuse sound fields are also successfully used to measure coefficient of sound scattering by embossed surfaces [9-13].

The theory of sound decay in rectangular rooms with a nonuniform distribution of sound absorption is well developed [14-21]: there are several approaches to calculating the total sound energy in a room. However, non-locality, i.e. the dependence of the decay curves on the measurement point, is not sufficiently developed. In this paper, the results of studying the non-diffuse sound field decay in a model experiment are presented, and the dependence of the measured decay curve on the location of the sound source and receiver relative to absorbing surfaces is analyzed.

2 Experimental setup

To study the decay in a rectangular-shaped room, a model with dimensions of 0.7x0.4x0.4 m was chosen. A detailed description of the experimental setup is given in [22], where it is shown that the ray approximation for describing the sound field in a room is valid at frequencies above 1500 Hz. Based on this, the measurement and evaluation of the decay curves were performed in the octave band with a center frequency of 4 kHz. The scheme of the experiment is shown in Fig. 1. To create an anisotropic field, two non-parallel walls are covered with sound absorbing material [10], in Fig. 1 these walls are hatched. Sound scattering elements can be located on one of the walls perpendicular to it, designated 1’ in Fig. 1, therefore, following [11–13], it is called a test one. The remaining three walls of the room, not shown in Fig. 1, are flat and rigid, i.e. there is mirror reflection of sound from them with a reflection coefficient close to 1.

To measure the decay sound curves, three positions of the source and nine positions of microphones were used, a total of 27 different combinations of the receiver and the source (Fig. 1). The loudspeaker was located in the dihedral corner of the room. The sound source used has a sufficiently wide radiation directivity to consider the sound field isotropic at the beginning of the impulse response. Nine different positions of the sound receiver were in the same plane parallel to the lower and upper walls of the room at approximately the same distance from them.

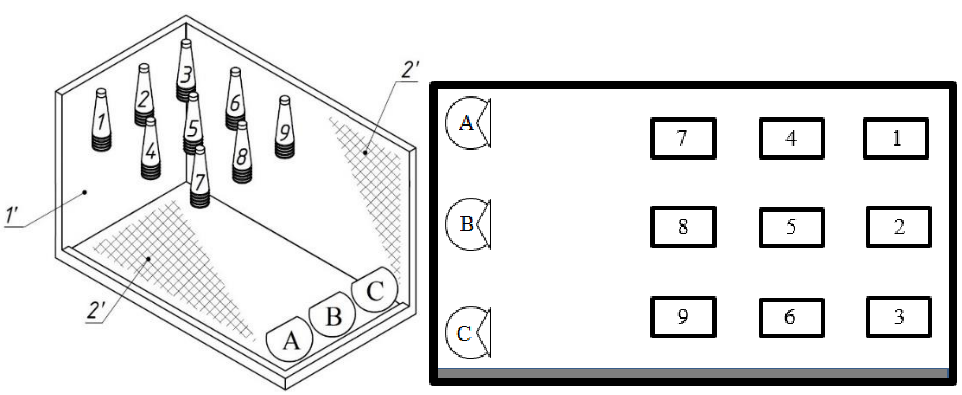


Fig. 1. Room model: A, B, C – sound source positions, 1-9 – microphone positions, 1' – test wall, 2' – walls with sound absorbing material.

A broadband excitation signal was supplied to the loudspeaker; an impulse response was extracted as a result of processing the signal recorded by the microphone. Then it was filtered in an octave band with a center frequency of 4 kHz and a decay curve was calculated, which was the final measurement result. Analysis of the influence of the loudspeaker and the microphone positions is carried out according to the measured sound decay curves.

The model experiment consisted of two stages. At the first stage, the influence of the relative position of the sound source and receiver was evaluated in the absence of sound scattering elements on the test wall, in this case the sound field in the room has the maximum anisotropy. At the second stage, the evaluation took place in the presence of cubic scatterers arranged in a staggered order, in this case the field is more diffuse [11]. However, in [11], measurements were only carried out at single position of the loudspeaker and microphone.

3 Reverberation time

3.1 Measurements in conditions of smooth test wall

For each combination of the source and receiver positions, a decay curve is measured, with which the reverberation times T20 and T30 are determined according to [4] in an octave band with a center frequency of 4 kHz. Fig. 2 shows the reverberation times T20 and T30 for each of the nine measurement points and for the A, B, C positions of the source. The wall covered with sound absorbing material is shown in Fig. 2 in gray.

The T30 value exceeds the T20 value for all source-receiver combinations, which indicates a nonexponential sound decay in the room. Moreover, with such a significant difference between the values of T20 and T30, the room reverberation time is not a uniquely determined quantity [4,5], however, we will use these values to characterize the rate of sound decay.

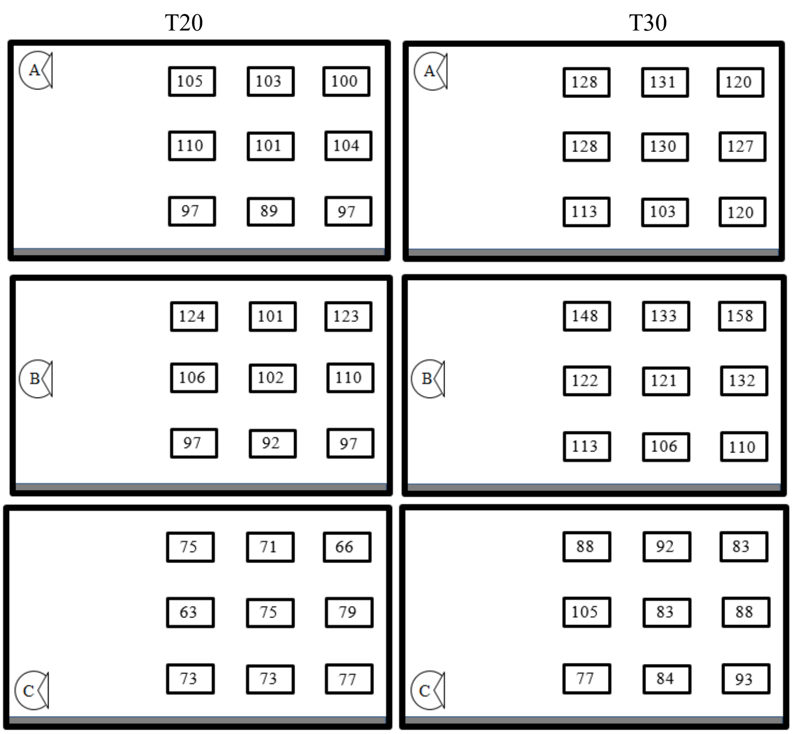


Fig. 2. Measured values of reverberation time T20 and T30 (ms) for different positions of the source and receiver in a room with a smooth test wall.

First of all, we should note that the measured values of the reverberation time are very different for various "source-receiver" configurations: the maximum T20 and T30 values are 124 and 158 ms, the minimum ones are 63 and 77 ms.

To estimate the spread of the measured values, statistical analysis of the obtained data was performed. Table 1 shows the average values of T20 and T30 between nine measurements for each A, B and C position of the source, the standard deviation (SD) and the coefficient of variation CV – the ratio of the SD to the average value, as well as these parameters for all 27 measurements. The largest spread of values is observed at the source position B, the smallest – at position A.

Table 1. Statistical data analysis (smooth wall).

Source Position	**T20**			**T30**		
	Avg, ms	SD, ms	*CV*, %	Avg, ms	SD, ms	*CV*, %
A	101.1	4.5	4.5	122.7	8.3	6.8
B	105.8	8.7	8.2	126.9	13.6	10.7
C	72.4	3.9	5.4	88.2	5.8	6.6
All measurements	93.2	14.1	15.1	112.8	17.7	15.7

3.2 Measurements in conditions of scattering wall

Similar measurements were carried out in the room with the test wall, on which 61 sound scattering elements are placed in the form of a cube 3.5x3.5x3.5 cm. Figure 3 shows the reverberation times T20 and T30 for various source-receiver configurations.

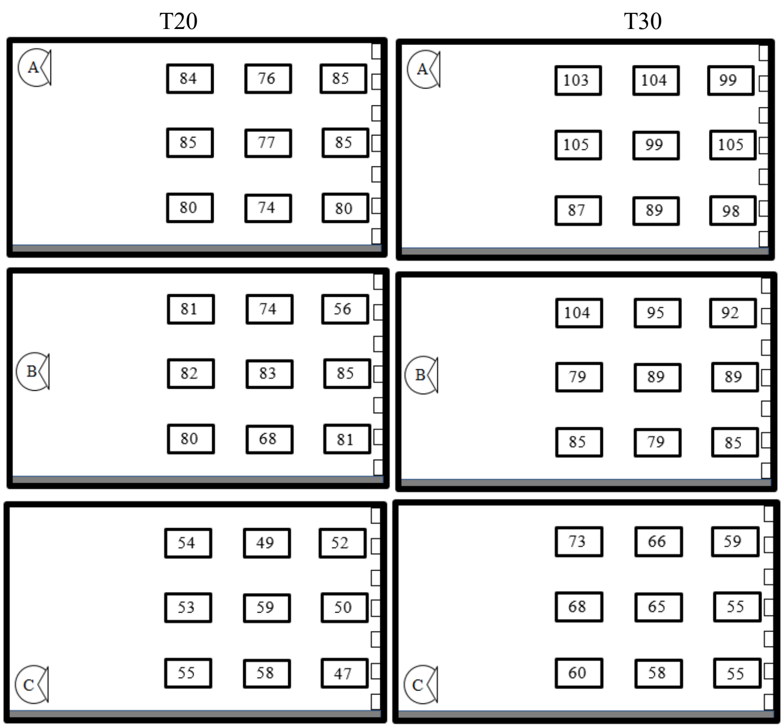


Fig. 3. Measured values of reverberation time T20 and T30 (ms) for different positions of the source and receiver in a room with a scattering test wall.

The values of T20 and T30 also differ significantly, therefore, the field with the introduction of sound scattering elements remains sufficiently non-diffuse.

The results of statistical analysis of experimental data are given in Table. 2. Firstly, there is a decrease in the reverberation time after installing the scatterers, this is due to the fact that the scattered sound falls on the absorbing walls and the sound energy in the room decays faster [11]. Secondly, the spread of absolute values, i.e. SD, has become smaller compared to a room with a smooth test wall, however, its relative spread, i.e. CV, has approximately the same values for T20 and significantly lower for T30 at the A and B positions of the source.

Table 2. Statistical data analysis (with scattering elements).

Source Position	**T20**			**T30**		
	Avg, ms	SD, ms	*CV*, %	Avg, ms	SD, ms	*CV*, %
A	80.8	3.6	4.5	99.0	5.0	5.0
B	76.8	7.0	9.1	88.3	5.8	6.6
C	53.2	3.0	5.6	62.6	5.3	8.5
All measurements	69.5	12.9	18.5	82.3	14.9	18.4

4 Decay curves

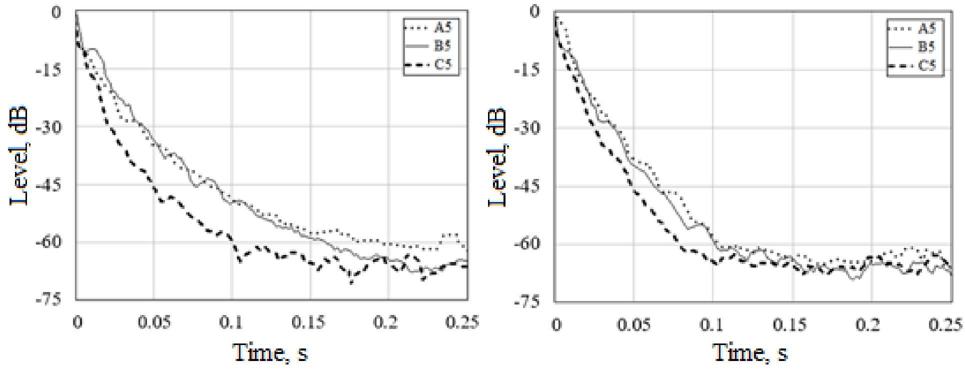
The influence of the source and receiver positions on the law of sound decay can be analyzed in more detail from a comparison of the decay curves. Symbols for the source and microphone positions are shown in Fig. 1. The results of comparing the decay curves for different "source-microphone" configurations are shown in Fig. 4-10 for the smooth test wall (a) and the test wall with scatterers (b). Each configuration below is indicated by a letter and a number, for example, A2 means that the source is in position A, and the microphone is in position 2. Let us analyze them.

Figure 4 shows the decay curves measured in the center of the area where the microphones were located (position 5) for three different source positions. For both types of walls, the decay curves when the source is located at positions A and B are close to each other, and the decay curve for position C closest to the absorbing wall differs significantly from them: it has a sharper slope. In the case of the scattering test wall, the decay curves are close to straight lines, i.e. decay occurs almost exponentially. It can be concluded that when the sound source approaches an absorbing wall, sound decay occurs faster.

Figure 5 shows the decay curves measured on a line (microphone positions 4, 5, 6) equidistant from the test wall, at one position of the source (position A). For both types of walls, the decay curves are slightly different from each other, while the decay of sound occurs faster when the microphone approaches the absorbing walls, although the obtained changes are smaller than when the source approaches the absorbing wall.

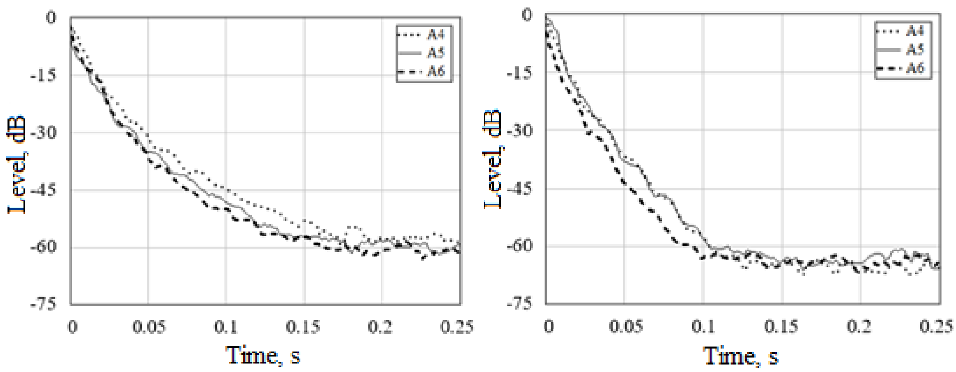
Let us consider the dependence of the decay curves on the longitudinal change in the microphone position. Fig. 6 shows the results of measurements at a central location of the source (position B) and microphones (positions 2, 5, 8). In general, the decay curves are close to each other, so the dependence of the decay curve on the position of the microphone along the central axis of the room is small.

 https://doi.org/10.1051/matecconf/202032000006



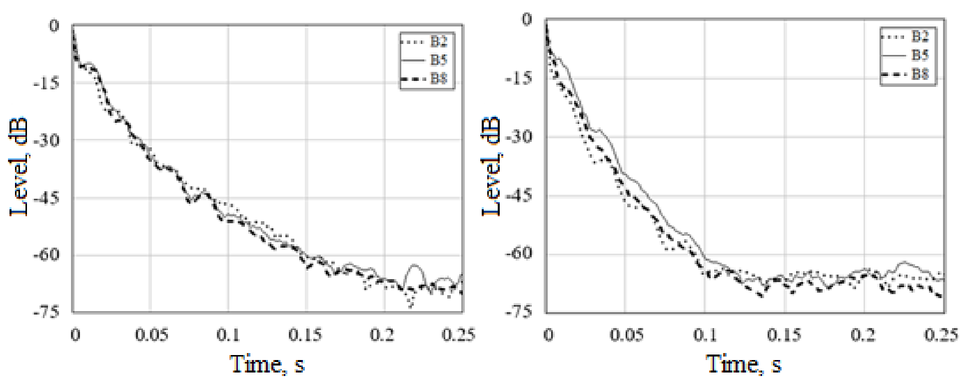
(a) (b)

Fig. 4. Decay curves for different positions (A B, C) of the source and microphone at position 5 with the smooth (a) and scattering (b) test wall.



(a) (b)

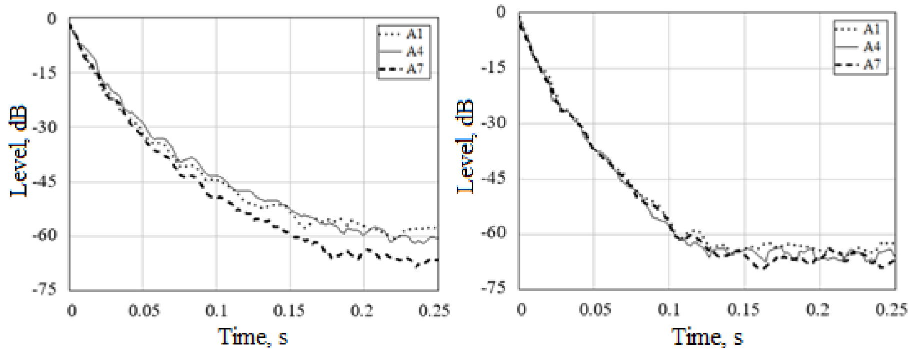
Fig. 5. Decay curves for the position A of the source and location of the microphone at positions 4, 5 and 6 with the smooth (a) and scattering (b) test wall.



(a) (b)

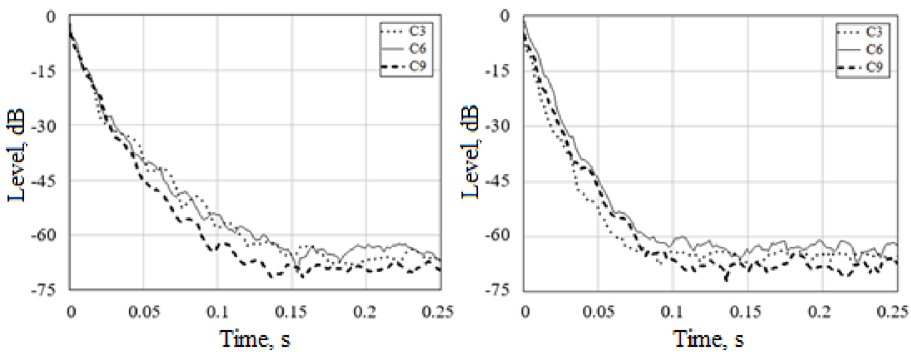
Fig. 6. Decay curves for the position B of the source and location of the microphone at positions 2, 5 and 8 with the smooth (a) and scattering (b) test wall.

Changing the location of the sound source changes the situation. Fig. 7 and 8 show the decay curves for the source located in the corners (A and C), and the sound receiver – along the room. As the microphone moves away from the smooth test wall, the drop in the curve becomes sharper. In the case of a scattering test wall at position A of the sound source, the position of the microphone does not affect the measurements, but at position C of the source this influence is noticeable.



(a) (b)

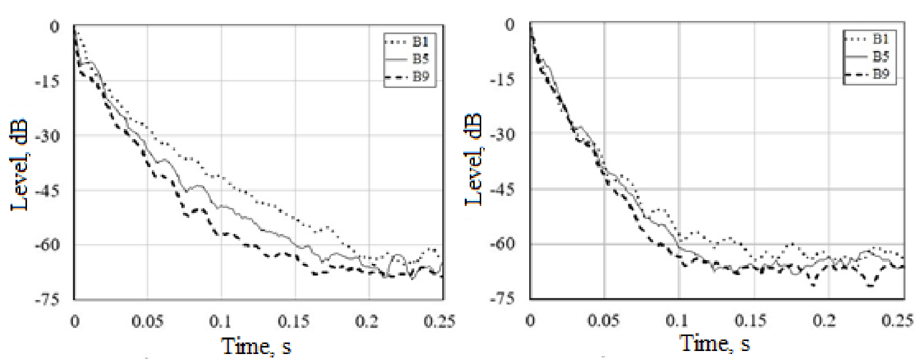
Fig. 7. Decay curves for the position A of the source and the location of the microphone at positions 1, 4 and 7 with the smooth (a) and scattering (b) test wall.



(a) (b)

Fig. 8. Decay curves for the position C of the source and the location of the microphone at positions 3, 6 and 9 with the smooth (a) and scattering (b) test wall.

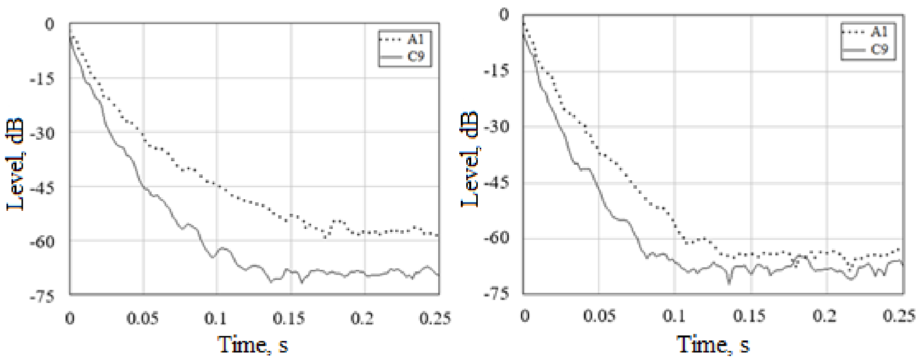
The largest spread of reverberation time values is observed when the source position B is in the room with the smooth test wall. This conclusion is graphically presented in Fig. 9.



(a) (b)

Fig. 9. Decay curves for the position B of the source and the location of the microphone at positions 1, 5 and 9 with the smooth (a) and scattering (b) test wall.

Fig. 10 shows the comparison of the decay curves with the fastest (C9) and slowest (A1) sound decay at the measurement point. Two decay curves characterize the spread of the 27 measurements: the remaining 25 decay curves are located between them.



(a) (b)

Fig. 10. Decay curves for different positions (A, C) of the source the location of the microphone at positions 1 and 9 with the smooth (a) and scattering (b) test wall, respectively.

5 Conclusion

This paper presents the results of a model experiment to study the decay of a non-diffuse sound field created in a rectangular room with two non-parallel absorbing walls. Sound decay curves were measured for 27 different positions of the sound source and receiver, which allowed to analyze the influence of their relative position on the measurement results.

A sufficiently large spread of the measured decay curves was obtained, as well as the values of T20 and T30, selected for characterizing the rate of sound decay. At that, increasing the diffusion of the sound field due to the placement of sound scattering elements on one of the walls of the room did not significantly affect the spread. It is established that the location of the sound source and receiver near the absorbing wall provides an increase in the rate of the decay.

Thus, the measurement of the characteristics of the non-diffuse sound field is very sensitive to the location of sound sources and receivers, which is also observed under field conditions [7]. In this regard, the theoretical approaches to the description of the non-diffuse sound field, which now do not predict the established laws, need to be clarified, and it is necessary to take into account the influence of sources' and receivers' position in conjunction with their radiation patterns in the experiment.

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