PRESENTS

Acoustics of the Great Hall of the Moscow State Conservatory after Reconstruction in 2010–2011

by N. G. Kanev, A. Ya. Livshits, and H. Möller

Introduction

The Great Hall of the Moscow State Conservatory was built in the early 20th century. For more than 100 years of service, it had a high acoustic reputation both among musicians and audience. By the beginning of the 21st century, the hall was in nearly critical condition. Thus, major renovation was needed. In terms of architectural acoustics, the main task was to keep the good acoustics of the hall. This paper presents the results of acoustic parameter measurements of the hall after Reconstruction in 2010–2011. The parameters of the hall measured before and after reconstruction are also compared. The comparative acoustic characteristics between the Great Hall and world leading concert halls are given.

The reconstruction of the Grand Hall of the Moscow Conservatory in 2010–2011 did not have a significant impact on its acoustics. The acoustic quality of the hall remained at the same high level, which has been confirmed by acoustic parameter measurements before and after renovation. Small differences in some parameters at low and high frequencies can be interpreted as positive, since they made it possible to balance the frequency response of these parameters. Performers and listeners appreciated the acoustics of the Great Hall after renovation. No one noted deterioration in the acoustic characteristics.

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Acoustics of the Great Hall of the Moscow State Conservatory after Reconstruction in 2010–2011

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Abstract—The Great Hall of the Moscow State Conservatory was built in the early 20th century. For more than 100 years of service, it had a high acoustic reputation both among musicians and audience. By the beginning of the 21st century, the hall was in nearly critical condition. Thus, major renovation was needed. In terms of architectural acoustics, the main task was to keep the good acoustics of the hall. This paper presents the results of acoustic parameter measurements of the hall after Reconstruction in 2010–2011. The parameters of the hall measured before and after reconstruction are also compared. The comparative acoustic characteristics between the Great Hall and world leading concert halls are given.

Keywords: architectural acoustics, acoustic measurements, Moscow Conservatory Great Hall

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DESCRIPTION OF THE HALL

The Great Hall of the Moscow Conservatory is located in the building designed by architect V.P. Zagorskii. The grand opening of the hall was held on April 7, 1901 [1]. Since its first days, famous musicians from both Russia and abroad performed there. The Great Hall rapidly gained a reputation as one of Russia's best music venues, in no small part because of its excellent acoustics, which has been remarked on by performers and listeners for over a century. Currently, the best soloists and ensembles in the world perform in the Great Hall. It also hosts international festivals and competitions, among them the world famous International Tchaikovsky Competition.

Let us describe the characteristics of the Great Hall that determine its acoustic properties. The hall has the classic rectangular shape, often called a *shoebox*, characteristic of concert halls built in the second half of the 19th and the first half of the 20th centuries [2]. The plans of the hall at the ground level and first two tiers of the amphitheater are shown in Fig. 1. The longitudinal and transverse sections of the hall are shown in Fig. 2. The hall has balconies along the longitudinal walls at the level of the first tier of the amphitheater. Interestingly, the angle of the first tier of the amphitheater is greater than that of the second tier (see Section 1–1 in Fig. 2), which is unusual from the architectural point of view. On stage, there is an organ, which almost completely overlaps the front wall of the stage space.

There are 1737 seats. In the seating area of the orchestra there are chairs with soft seats and backs, and on the balcony there are wooden benches with hard backs. The total length of the hall (from the organ to the back wall of the amphitheater) is 53 m, and the depth of the scene is 6 m. The width of the hall is 21.5 m, and the height of the orchestra seating area is 17.8 m. The volume of the hall is 15700 m^3. The specific volume per listener is 9 m^3.

The ceiling of the hall is flat and made of softwood boards attached to a wooden frame with approximately 50 cm offset from the camp ceiling. Linen fabric is glued on the ceiling boards. The surface of the fabric is puttied and painted. The joint of the ceiling and walls forms a quadrant vault with a curvature radius of approximately 3 m. The arches in the rear and side walls are made of fabric stretched over a wooden frame with a relative offset of about 5 cm. The arch in the front wall is made of puttied wooden planks. The walls of the hall are made of mortared brick and covered with decorative molding. There are seven windows in each side wall. The floor of the orchestra area is made of block oak over a solid floor of pine boards on logs. The air space under the floor is about 30 cm. Under each seat of the orchestra seating area, there holes have been drilled (about 12 30...40 mm holes) to supply air from the plenum beneath the area. The floor of the amphitheater is made of planks fastened to the wooden frame of the supporting structure of the amphitheater. In this case, there is a fairly large space under the floor, the height of which is from 0.5 to 2.5 m.

The acoustic parameters of the hall have been measured several times. The results of measurements car-

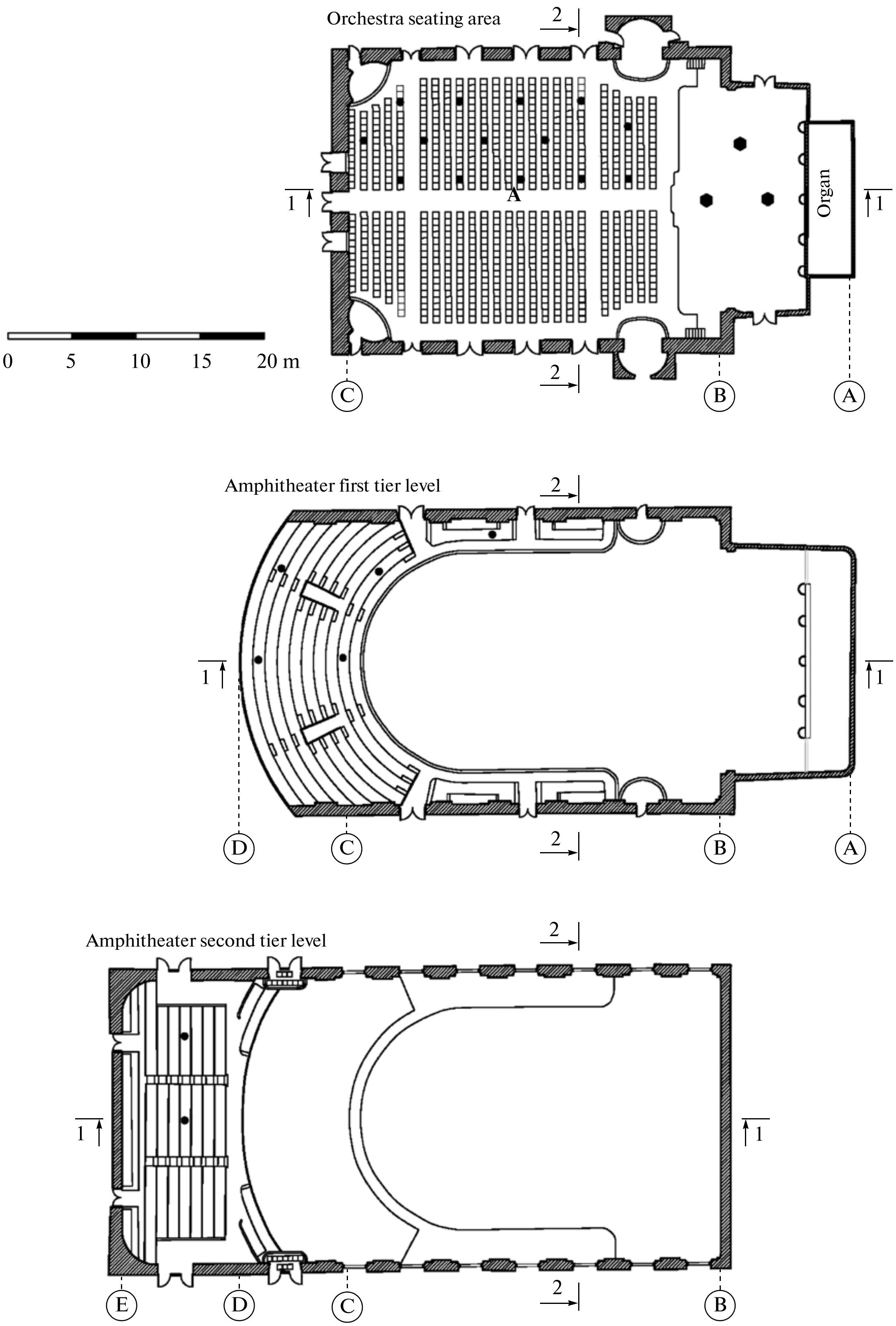

Fig. 1. Plans for Great Hall. Hexagons mark positions of the sound source on the stage, points indicate seats at which impulse responses were detected. The impulse response measured at point A is shown in Fig. 5.

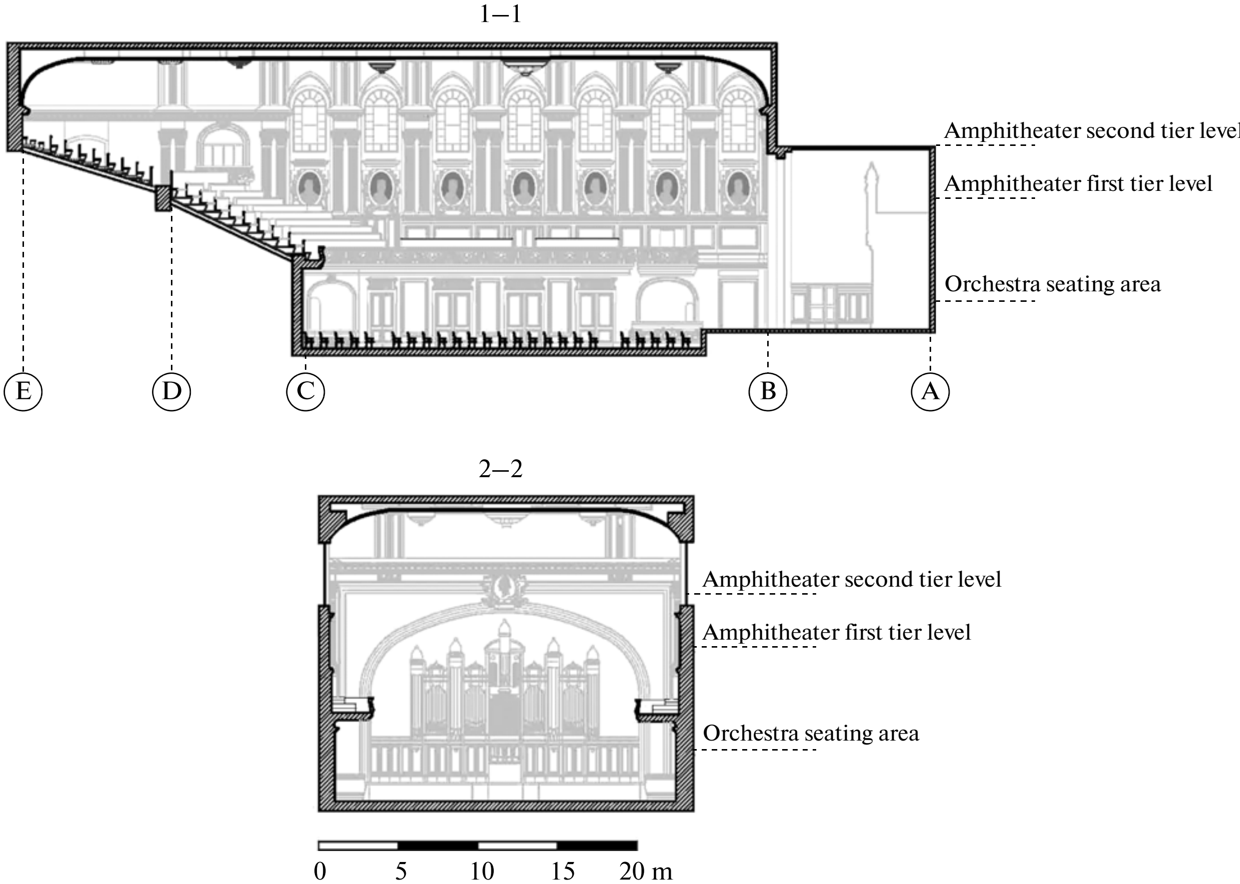

Fig. 2. Sections of Great Hall.

ried out in 1989 [3] and 2009 [4] have been published. Interestingly, the reverberation time of the Great Hall in 2009 was slightly less than in 1989 at low and high frequencies, while in the midrange it was the same.

2010–2011 RECONSTRUCTION

There has been no reconstruction of the Great Hall since its opening. Only emergency repairs and emergency response works were carried out. By the beginning of the 2000s, the state of the hall was insufficient for its full operation; i.e., the load-bearing structures of the balcony required replacement, the ventilation system did not provide necessary air exchange, and the interior decoration of the hall was in need of restoration. These and other works were planned as part of a large-scale renovation of the buildings of the Moscow Conservatory, which began in 2010. The reconstruction of the Great Hall began in May 2010 and ended in June 2011.

The main task of the reconstruction of the Great Hall in terms of architectural acoustics was to maintain its good acoustic properties. The reconstruction project did not envisage changes in the spatial planning of the hall. The interior decoration was preserved overall. Below is a list of what took place in the hall's reconstruction that to a greater or lesser extent may influence its acoustics.

The ceiling of the hall, made of wooden planks fastened to the wooden beams, remained in satisfactory condition. Few boards were replaced; the majority of them were preserved. Drying gaps between the boards (up to 15 mm) were hammered with strips of wood with bone glue, then peeled off and polished to a single smooth surface with the old boards. Supporting overlying structures of the entire ceiling shield made of wood were additionally strengthened with self-driving screws. Prime coats and leveling filler coats, reinforced with flax open-mesh fabric, were applied to the strengthened area. The canvas was replaced with a similar one and tightly glued to the puttied boards and painted. Thus, the ceiling design remained very close to the original in terms of performance, but from the acoustic point of view it became somewhat tougher. The fabric on the vaults between the ceiling and the walls were replaced. The walls of the hall and stucco were just refurbished. Finishing materials were not replaced except for a finishing layer of putty and paint.

The bearing structures of the amphitheater were in a critical condition, so they were completely replaced.

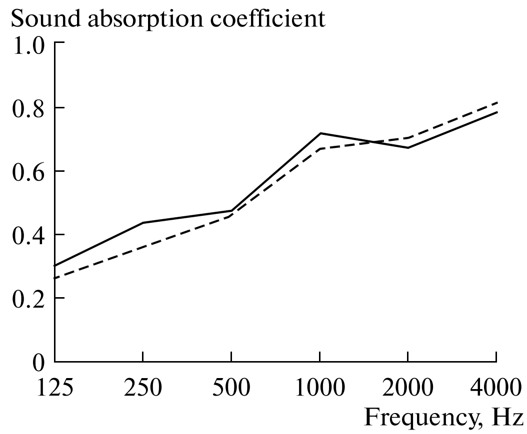

Fig. 3. Sound absorption coefficients of new (solid line) and original (dashed line) seats of chairs of the orchestra seating area.

The new supporting frame for seats is made of laminated wooden beams on which the "ladder" of audience rows is situated. The floor of the hall of the amphitheater is made of thick plywood on boarding joists. The flooring is oak block parquet glued to plywood.

In the design of the floor of the orchestra seating area, beams of timber were preserved on which flooring of 50-mm-thick planks coated with oak parquet was made. Instead of small vent holes under the seats of the orchestra seating area, 150-mm holes were drilled and air diffusers were mounted into them.

Chairs for the orchestra seating area and the seats for the balcony were made anew strictly according to the original designs. Materials for the soft parts of seats (seats and backs) were selected so that their sound absorption coefficient was as close as possible to the sound absorption coefficient of the original seats and backs. To this end, a series of comparative measurements of several seats of different designs were conducted in a reverberation chamber and the sample closest to the original was defined. Figure 3 shows the absorption coefficients of the selected sample of seats and results of the comparison with the original seat.

The design of the stage space was somewhat changed. The organ and its placement on the stage were preserved, but the height of the wooden panels of the walls of the scene was reduced to 2.8 m above the floor scene (Fig. 4). Above the wooden panels, the walls have been plastered and painted.

The fabric and design of the new harlequin and curtains of boxes were chosen so that they would better match the originals. The same applies to the runners laid in the aisles of the orchestra seating area.

In all reconstruction and restoration activities of the Great Hall, the group of supervisors on architectural and constructional acoustics carefully controlled the accuracy of the reconstruction project, the quality of work, and compliance of the materials with original ones.

RESULTS OF ACOUSTIC MEASUREMENTS

After the reconstruction of the Great Hall, acoustic measurements were conducted. They were taken on June 6, 2011, in the hall without an audience using the technique standardized under ISO-3382 [5]. An omnidirectional sound source (dodecahedron) was placed on the stage, 21 points were selected among spectator's seat uniformly distributed in the orchestra seating area and in the amphitheater. At these points impulse responses were measured.

Figure 5 shows the impulse response recorded at point A (Fig. 1) in the center of the orchestra seating area with the sound source located at the front of the stage. This is the reference point for determining the

(a) (b)

Fig. 4. Great Hall before (a) and after (b) reconstruction.

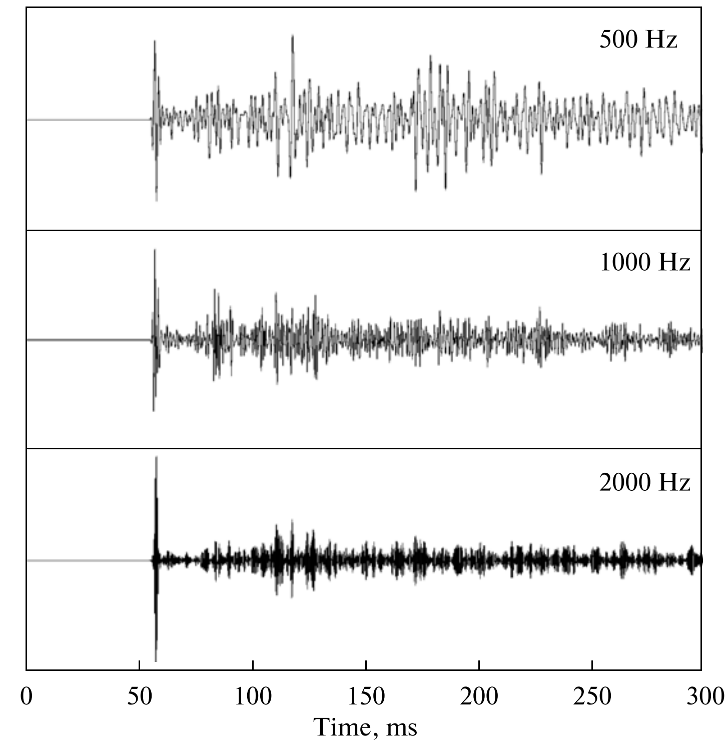

Fig. 5. Impulse response measured at point A (Fig. 1).

time delay of the first reflected sound (*ITDG*), which is one of the main acoustic parameters of the room [6]. The first reflection comes from the side walls and is delayed by 27 ms relative to the direct sound.

In order to characterize the acoustics of the hall, the following parameters calculated from the measured impulse response were chosen [5]:

1. The reverberation time *RT*, s, is the time during which the sound level declines by 60 dB.

2. The musical clarity index C_{80}, dB, is the ratio of the sound energy arriving in the first 80 ms to the residual acoustic energy, which arrives after 80 ms.

3. The sound strength *G*, dB, is the ratio of the sound measured at a receiver in the room to the sound level at a distance of 10 m played by a source in the free space [7].

4. The energy of early lateral reflections *LF* is the ratio of the signal received by a dipole microphone over a time period of 5–80 ms after the arrival of a direct signal, the null pattern of which is directed to the sound source, to the energy signal received in the first 80 ms by a nondirectional microphone. This parameter characterizes the spatiality of sound, since it corresponds to the fraction of energy coming to the listener from the side [8].

The results are compared with measurements made in the Great Hall shortly before reconstruction [4]. Figure 6 shows frequency dependences of the measured parameters before and after renovation.

The reverberation time *RT* after reconstruction was higher in the entire frequency range than before renovation. At low frequencies (125 Hz), it increased by about 25%, at a high frequency (4000 Hz) it increased by 40%, and in the frequency range of 250–2000 Hz it increased by approximately 10%. The balance of low frequencies, determined by $BR = (RT_{125} + RT_{250})/(RT_{500} + RT_{1000})$, was 1.16, while prior to the reconstruction it was 1.07. Interestingly, the reverberation time after reconstruction was closer to the one measured 20 years before. [3] The reverberation time in the hall with an audience was calculated by the method proposed in [9]. Figure 7 shows the frequency dependences of the reverberation time measured in an empty hall and calculated in a filled hall based on the results of these measurements. The balance of low frequencies for the hall with the audience is 1.18. Figure 7 also shows for comparison the results of measurements in the hall with and without an audience in 1989 [3]. It is typical of the Great Hall that the acoustic parameters change significantly when it is filled with people, which is characteristic of such halls with a relatively high reverberation time (for example, Grosser Musikvereinssaal, Vienna).

Musical clarity index C_{80} hardly changed at all at frequencies 250–1000 Hz. But at the low and high frequencies, there is a decrease of C_{80} by about 2 dB, which correlates with the increase of the reverberation time at these frequencies.

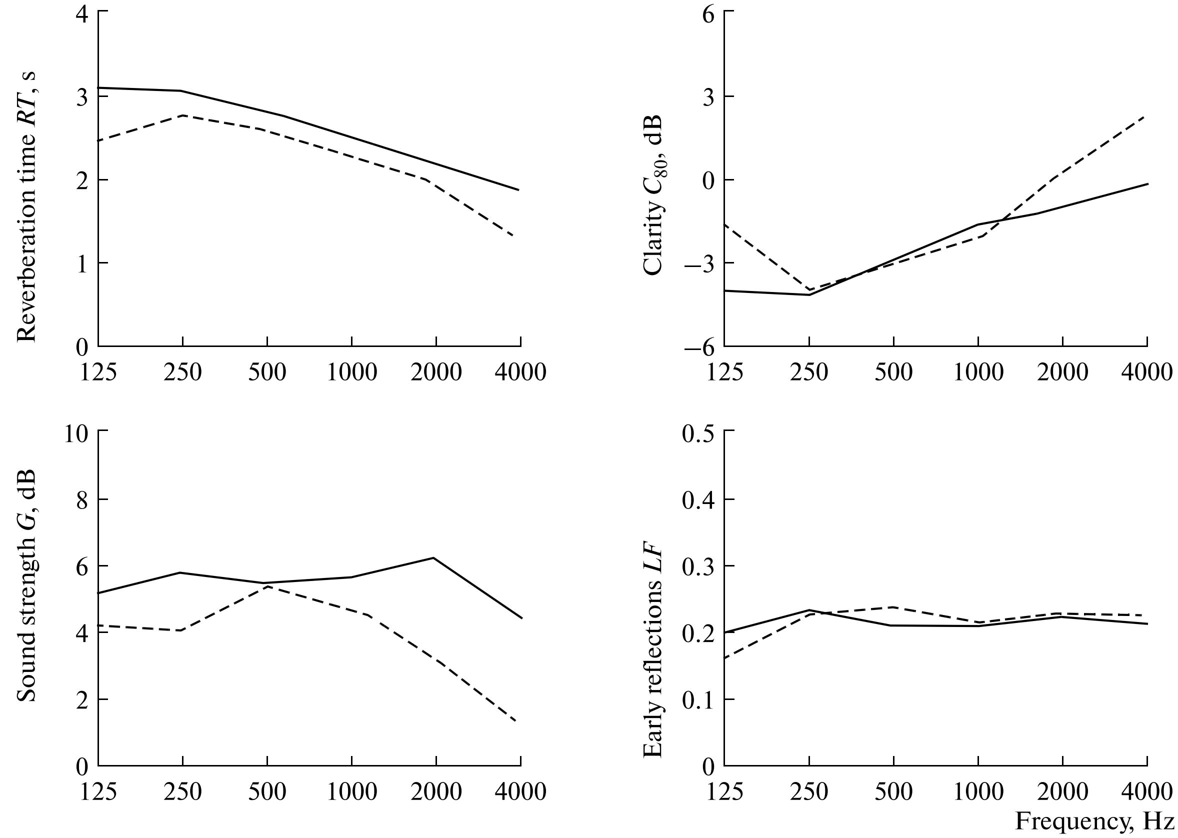

Fig. 6. Results of measurements of acoustic parameters of Great Hall after reconstruction (dotted line refers to measurements before reconstruction according to [4]).

The difference in sound strength G before and after reconstruction in the frequency range of 125–1000 Hz is less than 1.5 dB. Taking into account that this value may range from 1 to 1.5 dB depending on the measurement method [6, 10], we can conclude that there is no significant change in sound strength at these frequencies. However, at high frequencies (2000–4000 Hz), the sound strength increased by about 3 dB, which is a noticeable change. At the same time, the frequency dependence of the G parameter was more balanced.

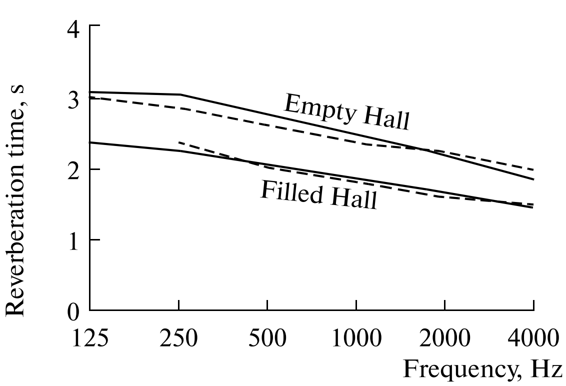

Fig. 7. Reverberation time of Great Hall with and without audience in 1989 (dotted lines) and 2011 (solid lines).

The energy of early lateral reflections LF measured before and after reconstruction has similar values. The slight decrease in the LF parameter at low frequencies can be because of increased stiffness of the ceiling after reconstruction and, consequently, increased sound energy reflected from the ceiling.

Analysis of the measurement results shows that the objective acoustic properties of the Great Hall after reconstruction changed slightly in the midrange, while at low and high frequencies, changes are more pronounced. The increase in low-frequency reverberation time is primarily because of the increased rigidity of certain structures, i.e., the ceiling and the floor of the amphitheater, as well as a decrease in the number of wooden panels on the stage. The restorative sealing of cracks and layer separations on plastered surfaces, tight bonding of the canvas on the ceiling, and removal of dust from walling reduced absorption at medium and high frequencies.

Concerts in the Great Hall after renovation made it possible to obtain the first subjective evaluations of its acoustics. We list the remarks of some musicians who performed in the hall.

Table

Concert Halls	Volume, m^3	Number of seats	RT*, s	BR*	C_{80}, dB	G, dB	$ITDG$, ms	LF
Great Hall of the Conservatory, Moscow	15700	1737	1.95	1.18	–2.4	5.5	27	0.22
Grosser Musikvereinssaal, Vienna	15000	1680	2.00	1.11	–4.3	7.8	12	0.18
Concertgebouw, Amsterdam	18780	2047	2.00	1.09	–3.6	6.4	21	0.18
Symphony Hall, Boston	18750	2625	1.90	1.03	–2.6	5.4	15	0.20
Abravanel Hall, Salt Lake City	19500	2812	1.75	1.06	–2.0	2.6	30	
Konzerthaus, Berlin	15000	1575	2.05	1.08	–3.1	6.9	25	

D.A. Khvorostovskii, baritone: "The renovated Great Hall of the Conservatory is an acoustically excellent hall. The sounding of the voice in it became livelier, an unrestricted sound distribution is felt when singing."

V.I. Fedoseev, Chief Conductor of the Moscow Radio Symphony Orchestra: "A hall with excellent acoustics, but after renovation it has become more demanding of the performers."

Yu.A. Bashmet, Chief Conductor of the New Russia State Symphony Orchestra: "Beautiful hall, amazing acoustics, it becomes a little softer and will reach its full splendor."

The majority of surveyed listeners said that the Great Hall after reconstruction became better in acoustic terms. According to some reviews, at full capacity it sounded like a beautiful musical instrument.

The marked improvement in the sound of the hall according to subjective evaluations can physically be because of the increase in the reverberation time and low-frequency balance, as well as due to the equalization of the volume frequency response.

It is interesting to compare the acoustic parameters of the Great Hall with those of other famous concert halls. For comparison, five rectangular halls with the highest rating (A+ and A) according to subjective assessments of musicians and listeners were chosen [11]. Table shows the mean mid-frequency (500 and 1000 Hz) values of the reverberation time RT, bass balance BR, musical clarity index C_{80}, sound strength G, delay time of first reflection $ITDG$, and energy of early lateral reflections LF. The values of the reverberation time and low-frequency balance (marked with asterisks) are given for a hall with an audience. All halls shown in the table have similar values for almost all the acoustic parameters. Only the low-frequency balance BR of the Great Hall has a greater importance than in other halls: the mean value for the five halls is 1.07. In terms of subjective perception, higher values correspond to a "warmer" sound. [6]

CONCLUSIONS

The reconstruction of the Grand Hall of the Moscow Conservatory in 2010–2011 did not have a significant impact on its acoustics. The acoustic quality of the hall remained at the same high level, which has been confirmed by acoustic parameter measurements before and after renovation. Small differences in some parameters at low and high frequencies can be interpreted as positive, since they made it possible to balance the frequency response of these parameters. Performers and listeners appreciated the acoustics of the Great Hall after renovation. No one noted a deterioration in the acoustic characteristics.

It should be noted that over time, there may be some changes in the acoustic parameters of the hall, primarily because of stabilization of the temperature and humidity in the hall, elapse of the first rapid aging phase of individual building materials (paints, fillers, adhesives, and primers); release of excess moisture from wooden structures, cement-sand screeds, and concrete; and final nail fixation and lapping of nail and self-drilling compounds in wooden structures. The problem of acoustic evolution of halls after construction or reconstruction has not been sufficiently covered in the current literature and is of independent interest. In connection with this, a series of measurements of acoustic parameters of the Great Hall at six-month intervals is planned. These measurements should also record the presence or absence of differences in acoustic parameters of audience halls in summer and in winter, when the temperature and humidity characteristics of fresh air differ greatly.

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