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ACOUSTICS OF THE HERMITAGE THEATRE IN ST PETERSBURG

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1. INTRODUCTION

There is a widespread opinion, that acoustics of old halls is always good in spite of their architectural decision and employment. Sometimes this opinion refers to the halls, which are not used during a lot of decades, and there are no alive witnesses of their "good acoustics". Such a problem is very important in Russia, where a lot of palaces, palace and park buildings and churches were closed, altered or even ruined after 1917. Now when many of them (being the monuments of architecture) are renovated, it's necessary to investigate their acoustical characteristics and try to establish a good sound quality. We must note, that many of such halls should be used not only for concerts of classical music but also with other purposes. That's why sound reinforcement systems should often be installed. All this makes a rather difficult problem to estimate a good sound quality in the old halls, where the primary interior should not be altered due to the modern acoustical demands. That's why it's interesting to investigate the acoustics of the recently reconstructed the Hermitage theatre - a part of the known all over the world complex of buildings of the Winter Palace in St.Petersburg.

2. DESCRIPTION OF THE HALL

The Hermitage theatre was built in St.Petersburg according to the project of G.Quarenchi in 1783-1787 [1,2]. It is one of the oldest in Russia among the survived theatre halls nowadays. The hall is a unique architectural monument. It's interior was not changed in general since the end of the XYIII-th century. The plan and the longitudinal section of the hall are shown in Fig. 1 and 2. The hall looks like an amphitheatre in the form of a semicircle, that is 20 m in diameter with 6 rows of seats. In the centre of the amphitheatre there is a little semicircle that is 5.5 m in diameter with no seats. Three staircases start from this little semicircle; one of them is the central, and the other two - lateral.

In the XYIII-th century the seats area was limited by the barriers of the lateral staircases. Besides, a very narrow orchestra pit was situated behind the barriers. As a result of several reconstruction the part of the hall, situated near the stage was altered. The border of the stage (footlights) had been removed to the stage volume, the orchestra pit became more wide, and three rows of seats had been installed before the pit. Nowadays the length of the hall from the footlights to the back wall is equal to 18 m. The hall is 11 m high in average. There are seats for 300 persons in the hall. Mostly all the surfaces of the hall are made of stone. Along the upper border of the amphitheatre there are several marble columns and sculptures in the niches.

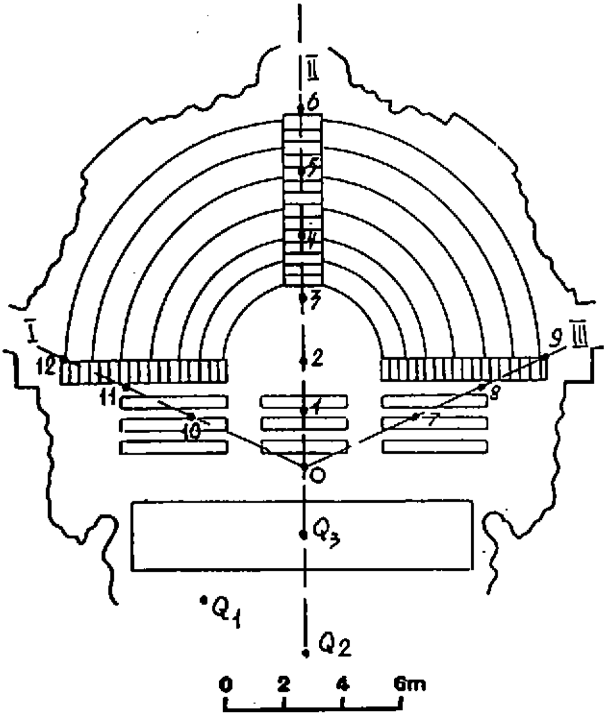

Fig.1. Plan of the hall.

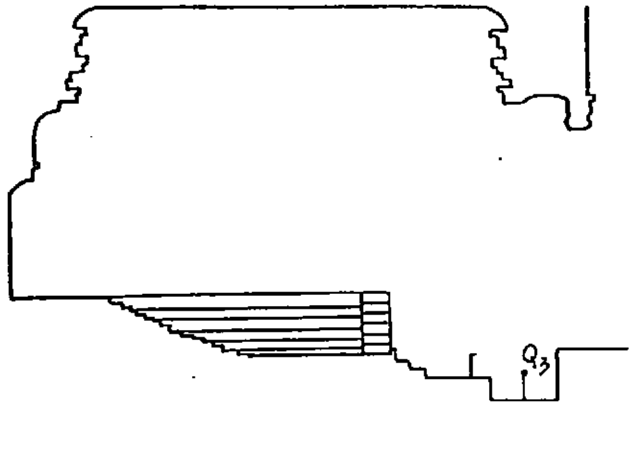

Fig. 2. Section of the hall.

3. METHOD

All the measurements were made in the empty hall. A calibrated pistol shot was used as an omnidirectional sound source. The hall now is used in two regimes. First of all it is used as a lecture hall of the Hermitage museum. In such a case the stage is closed by a large projection screen. In the second case the opera and musical concerts take place in the hall. In this way two series of measurements were held. In series 1 the stage was closed by the projection screen and the pistol shots were produced from the point Q_1, where a speaker was usually standing. In series 2 the stage was open and the shots were produced from the point Q_2 on the stage and from the point Q_3 in the pit. Additional series 3 was used for measurement of the reverberation time on the stage.

Two omnidirectional microphones were used. One of them was always installed in the point 0, and the other in the points 1-12 (see fig. 1). The signals from both microphones were recorded on the professional 2 channel tape-recorder. Recorded in such a way impulse responses of the hall $p(t)$ were digitised with the help of the ADC and stored in the memory of the IBM-PC computer. As a result the following acoustical characteristics were received:

1. Reverberation time T_{60}.
2. Clarity index $C_{80} = 10\lg[\int_0^{80ms} p^2(t)dt / (\int_0^{1500ms} p^2(t)dt - \int_0^{80ms} p^2(t)dt)]$.
3. Definition index $D_{50} = 10\lg[\int_0^{50ms} p^2(t)dt / \int_0^{1500ms} p^2(t)dt]$.
4. Structure of sound reflections
$L(t) = 10\lg[p(t) / p_{max}(t)$.
5. Energy decay curves (EDC).
6. Energy increasing curves $W(t) = \int_0^{t} p^2(t)dt / \int_0^{1500ms} p^2(t)dt$
7. Distribution of the sound energy along the axes I,II, III (see Fig.1)
$\Delta E = 10\lg \int_0^{1500ms} p_0{}^2(t)dt - 10\lg \int_0^{1500ms} p_i{}^2(t)dt$,

were the low $p(t)$ index "0" marks the position of the microphone in the point 0 and index "i" - the position in the following points: 1-6 on axis I; 7-9 on axis II and 10 - 12 on axis III. The values of ΔE were estimated for the different octave bands. The analysis of ΔE may be useful for the indirect estimation of the timbre.

4. RESULTS

The values of T_{60} are shown in Fig.3 and the values of C_{80} and D_{50} -in Table 1. Two examples of the structure of sound reflections $L(t)$ are given in Fig. 4,5. In Fig. 6 are presented some ΔE values for the different distances r between points 0 and i.

5. ANALYSIS

It can be seen from Fig. 3 that in both cases, when the hall is used, the reverberation time is quite the same and is equal to 1.6 s (in the frequency band 0.5-2 kHz). As it was mentioned, the measurements had been made in the empty hall. So, while using the known formulas of the statistical theory [3], the correction was made for the presence of 210 people (70% of the hall's capacity). In such a way it was estimated that at the low frequencies the reverberation time of the occupied hall will be 1.4 s and at the middle frequencies - 1.3 s.

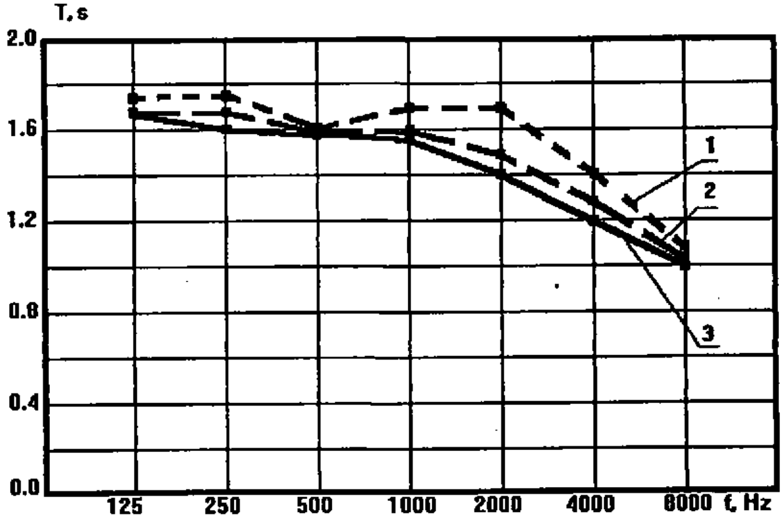

Fig. 3. The values of reverberation time. Numbers 1,2,3 correspond to the series of the measurement.

According to the modern recommendations, the reverberation time for the musical theatres of such a volume in the middle frequencies must be 1.4 s, and for lecture halls - 1.1 s [3]. Thus, the optimum of the reverberation in the hall during opera is provided, but there is an excessive reverberation for speech usage.

In Table 1 besides the measured values of C_{80} and D_{50} there are presented the mean values over the hall and standard deviation. The received results prove, that in some parts of the hall the values of C_{80} exceed the recommended optimum in -1 - +3 dB. One can explain these exceeding by the visible preference of the direct sound, that cause some dryness of the music in the hall.

Table 1. The values of C_{80} and D_{50}.

Microphone position	Series number, source position					
	1, Q_1		2, Q_2		2, Q_3	
	C_{80}, dB	D_{50}, dB	C_{80}, dB	D_{50}, dB	C_{80}, dB	D_{50}, dB
M-1	2.3	-4.8	2.6	-5.2	2.4	-6.1
M-2	1.5	-5.6	2.1	-6.1	3.6	-8.6
M-3	2.7	-6.6	0.4	-6.5	3.2	-8.5
M-4	2.3	-5.8	0.7	-5.3	4.3	-7.6
M-5	1.9	-4.8	3.1	-5.4	1.6	-5.2
M-6	3.6	-6.2	4.6	-7.2	3.9	-6.8
M-7	3.8	-6.4	5.3	-7.8	3.8	-6.6
M-8	1.5	-4.7	-	-	-	-
M-9	3.7	-6.6	-	-	-	-
M-10	5.4	-9.0	-	-	-	-
Mean value	2.9	-6.0	2.7	-6.2	3.3	-7.0
s.d.	1.2	1.3	1.8	0.9	0.9	1.2

The values of the definition index $D_{50} < -5$ dB practically all over the seats area. Due to the known relation between D_{50} and the articulation of the syllables S one can expect the values of S=70-75% that is equal to the satisfactory intelligibility of speech in the hall. These data are in good agreement with the results of the articulation listening tests in the hall. They showed the intelligibility of speech from satisfactory till good with the preference of the first.

The analysis of $L(t)$ showed that the structure of early sound reflections on the main area of the seats is rather satisfactory. The typical example (with the source in Q_2 and the microphone in point 11) is given in Fig. 4 When the source is placed on the longitudinal axis (Q_2 and Q_3) in the central part of the hall (points 2,3,4) one can see a concentration with the delay about 70 ms. The reason of its formation is connected with the focusing action of the curved walls of the hall. Fig. 5 shows (the source is in Q_3; microphone - in point 2), that the level of the concentration is commensurable with the direct sound.

The distributions of ΔE show, that when the source is placed on the longitudinal axis in the depth of the stage (Q_2), the process of sound transmission is rather smooth in the area of the hall as well as in different frequency bands. From the other side, during the lectures when the source is placed in Q_1 the distribution of ΔE is much more irregular. The values of ΔE along axis II and III for the position of the source in Q_1 and Q_2 as an example are shown in Fig. 6. The subjective listening of music let us think about a rather high quality of sound in the hall. But during the concerts (when musicians are on the stage), the rating of balance and the timbre appeared to be higher, than during operas. The last are in a full agreement with the results of the objective measurements.

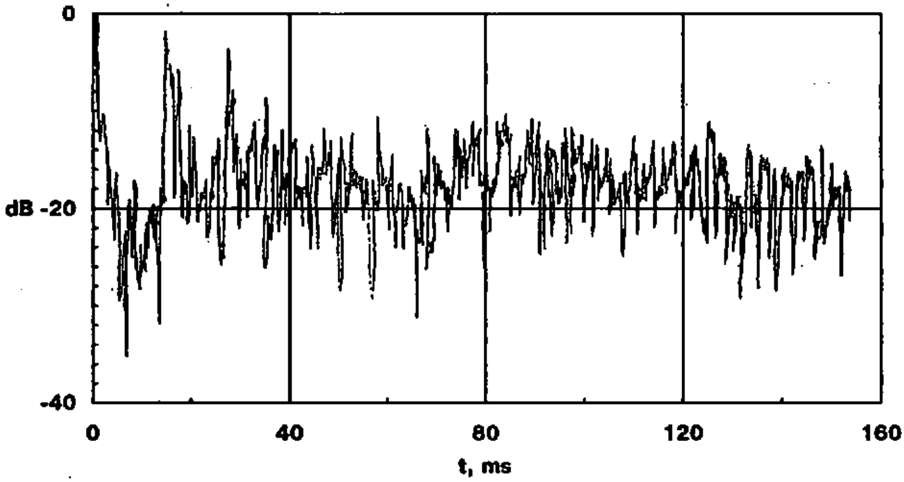

Fig. 4. $L(t)$ measured in point 11 (sound source in position Q_2).

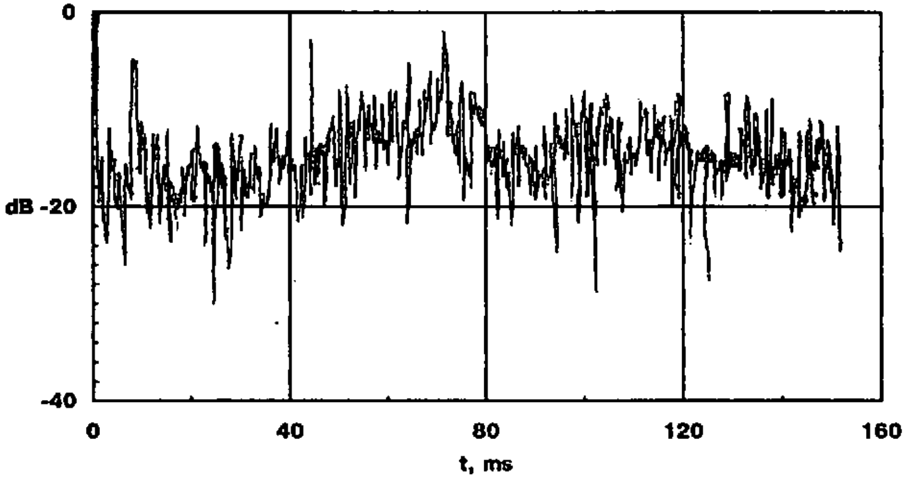

Fig. 5. $L(t)$ measured in point 2 (sound source in position Q_3).

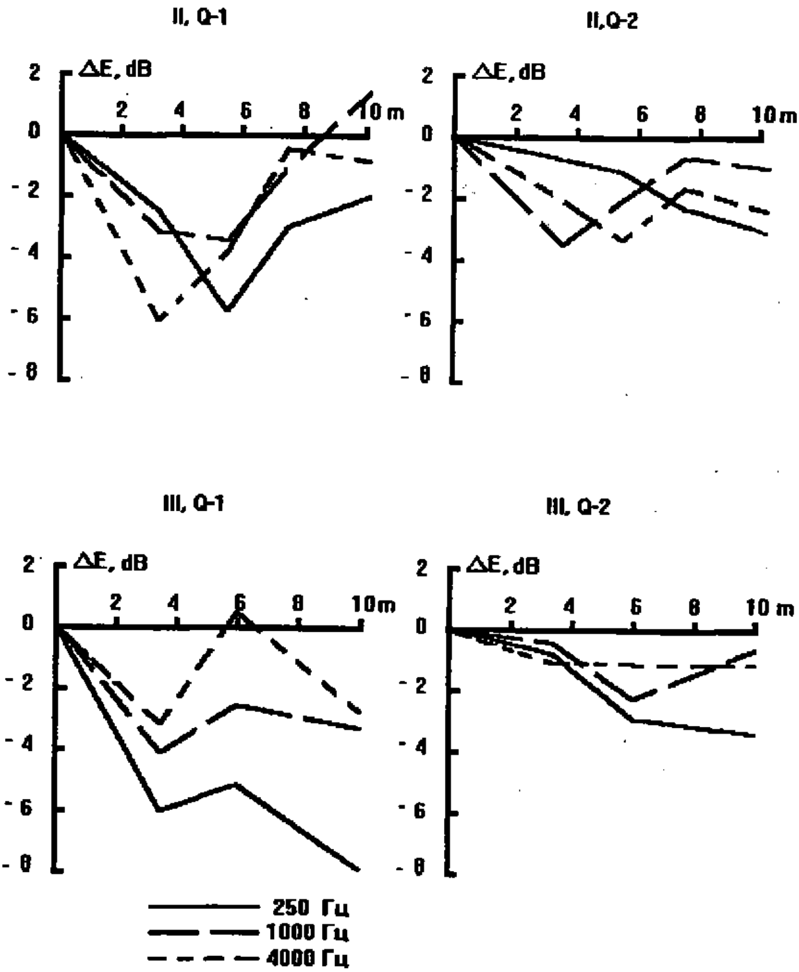

Fig. 6. Distribution of the sound energy along the axes II and III.

The problem of sound reinforcement in the hall lays behind the aim of this paper. But it should be noted, that it's impossible to provide sufficient speech intelligibility without sound reinforcement, when lectures are being provided in the hall.

6. REFERENCES

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