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Architectural Acoustics in Russia

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ABSTRACT

A historical review of the architectural acoustics in Russia is presented. Three periods are to be cleared out. The early period is from the beginning of 30-th years till to the end of 40-th years, the next one is up to the end of 80-th years, and the last is the modern period. Three main topics have been reviewed for each period: scientific studies, measurement techniques and practical works on acoustic consulting. Mostly attention is paid to various theatres, concert halls, studios, cinema and sport halls which have been designed by the Russian acousticians. The detailed bibliography on the subject is given as well.

INTRODUCTION

The main purpose of this paper is to introduce the bibliography of the Russian investigations on architectural acoustics. There was only one publication on this subject [1]. It dealt with the early period and included the bibliography up to the end of 40-th. So the presented bibliography covers the period from the beginning of 50-th till 2001. The review is organizes as following. In sections 1-3 the investigations on room acoustics during three time periods are discussed. The principals of the bibliography are presented in Appendix 1.

1. EARLY PERIOD (1921-1949)

Although the bibliography of that time period is published [1] and so is not presented in this paper, it seems reasonable to give a brief review on these early investigations.

1.1. Research studies on architectural acoustics

The studies on room acoustics began in Russia in 1920-1921 and were headed by prof. S.Lifshitz. In 1923 he published the first students' text book on the subject. He was also the first Russian acoustician who developed the devices for reverberation time measurements. Later prof. S.Lifshitz was very active with studies on the optimal values of reverberation time. He published several papers on this subject and proposed the analytic relation between the optimal reverberation time and room's volume. The theoretic approach to the process of reverberation was presented in studies of M.Machinsky, G.Chigirinsky, L.Rozenberg and M.Sapozkov. The two last scientists studied in all the details the reverberation in coupled rooms. I.Dreizen was the first to study the wave theory of the sound fields in the rooms with sound absorbing surfaces. L.Brehovskih's theoretic researches were important for the estimation of the conditions when the geometrical methods such as mirror source method may be used in room acoustics.

The problem of perception of reverberation was also studied by prof. S.Lifshitz who estimated the frequency dependence of reverberation time. This problem was also investigated by G.Goldberg, S.Ter-Osipiantz and A.Rabinovich who introduced the so called "effect of distance" in radio studios. They studied the perception of reverberation when the sound source was placed on different distance from the microphone. The reverberation curves were watched on an oscilloscope. It was estimated that the process had a drop after the direct sound and early reflections that is followed by the exponential decay due to the room's reverberation. This led the acousticians to propose the so-called "effective" or "equivalent" reverberation that can describe such process. The ratio of direct sound energy to the

energy of diffuse sound field was also investigated by I.Deizen and V.Furduev. The perception of echo was the subject of the work done by A.Rabinovich. He studied the influence of echo on speech intelligibility in the free sound field.

1.2. Acoustic design

The development of broadcasting caused the necessity of building various studios. There was no experience of such works before. So new acoustic laboratory was organized in 1931. Russian acousticians (Y.Suharevsky, I.Dreizen, S.Ter-Osipiantz) did a lot of work and published the fist recommendations on the design of studios. Later in 1934 a special research center that is now called the Research Institute for TV and Radio (VNIITR) was organized and headed by I.Goron. The later was responsible for the building of the first large professional broadcasting center in Moscow that was called the State House of Broadcasting and Sound Recording (GDRZ). This center included 3 musical studios (V=4800 m^3, V=2230 m^3,V=879 m^3) and a lot of various small talk studios and control rooms. Prof. S.Rjevkin, G.Goldberg and the scientists mentioned above participated in this design. The building of GDRZ was a great success. For the first time there were developed new sound absorbing materials that were installed in the studios. Special constructions for sound insulation were proposed. Tools for variable acoustic in the form of rotating columns were provided in one musical studio. The studios and control rooms had good acoustics and were widely used for sound recording and on air broadcasting.

The other branch of acoustic design dealt with the cinemas and studios for motion picture production. The acoustics of these rooms was investigated by A.Indlin and A.Kacherovitch. The studies were organized in the Institute of Motion Picture Engineers (LIKI, Leningrad) and Research Institute for Motion Picture and Photography (NIKFI, Moscow). A.Kacherovitch was the most active in this field. He had published several books and papers on the acoustic design of dubbing studios and cinema halls. He also was responsible for the design of studios that were successfully used on the largest centers of film production in Moscow and Leningrad.

The situation on the design of theatres and concert halls was not so successful as in the case of broadcasting and motion picture. At first it should be mentioned that such buildings were rarely built during the early period. From the end of the civil war in 1921 and up to the end of 40-th only 25 theatres were built in Russia and new large concert walls were not built at all. Some of these theater halls had poor acoustics. A typical example is a huge building of the opera house in Novosibirsk. A large hall for 2000 seats had a form of a circle covered with a dome. Another example of a hall with acoustic faults is a drama theatre for 1200 seats in Rostov-on-Don that was also designed with a circular plan. It is interesting to note that some halls with rectangular plan (opera houses in Tashkent and Alma-Ata) having been built at that period had good acoustics. The authors were not able to find any information on the participation of the Russian acousticians in the design of these 25 theatre halls. It seems that only architectural demands were of the importance.

It is necessary to mention another building that was never built but had a great influence on the development of the architectural acoustics in Russia. At the beginning of 30-th in was decided by the party leaders of the country to build in Moscow a huge palace of congress that was called Dvoretz Sovetov. Several architectural competitions were held. Due to the final project it should be a large basement with a huge Lenin's monument at the top. There were planned two halls in the basement: a large hall for 20000 seats and a small hall for 5000 seats. The large hall was in the form of the circle covered with a dome. The congresses of the communist party should take place in this hall. It was quiet clear that nothing could be heard in such a large hall without sound reinforcement. So the great attention was drawn to the problem of acoustics. There was organized a special institution responsible for the design of Dvoretz Sovetov. It included an acoustic research center for the investigations on room acoustics, sound insulation, noise control and sound reinforcement. Most of the Russian acousticians mentioned above were employed in these studies. A lot of important investigations were done and published by them. The studies of sound absorbing materials for the dome of the hall (G.Malujinetz, N.Andreev, S.Rjevkin), sound insulation (I.Leizer), sound reinforcement (A.Rimsry-Korsakov, V.Grigoriev, L.Rozenberg, B.Tartakovsky, V.Furduev, Y.Suharevsry, G.Goldberg) can be mentioned. So the design of Dvoretz Sovetov was an important stimulus for the development of room acoustics in Russia.

1.3. Acoustic measurements

The studies on acoustic measurements in room acoustics dealt mainly with the estimation of reverberation time. Several methods were proposed and various devices were designed. These methods were studied theoretically in the publications of A.Harkevitch, G.Goldberg and M.Sapozkov. Two methods for reverberation time measurements were used in most cases. The first was based on a record of reverberation curve by the level recorder. In the second method the reverberation curve was observed on the oscilloscope. The devices for these measurements were proposed by G.Goldberg, Z.Mitiagina, Z.Pezviakova and other scientists.

2. MIDDLE PERIOD (1950-1991)

Most of the investigations in room acoustics during that period were done in three Moscow based institutes. NIKFI's acoustic laboratory dealt mainly with the design of cinemas and studios for film production. It has directed by A.Kacherovitch. After his death in 1977 the researches were done by two small groups. One of them was headed by Y.Indlin and his colleague Y.Kozlov, and the other by Y.Grebeshkov. VNIITR's acoustic laboratory was responsible for the design of TV and radio studios. During this period it was headed by S.Ter-Osipiantz, K.Krastin, V.Lebedev and M.Lannie. The new research center NIISF (Research Institute of Building Physics) was organized at the beginning of this period. Its acoustic laboratory dealt mainly with the design of theatre, concert and multi-purpose halls and was headed by V.Furduev and later by L.Makrinenko.

2.1. Research studies on architectural acoustics

Geometrical methods were widely used in NIKFI for the estimation of the structure of sound reflections [2,7,12,13,21,24,30,40]. The simple forms of the rooms typical for the cinemas were analyzed in details. A.Kacherovitch introduced the so-called "surfaces of 1-st and 2-nd order reflections". The sound reflections reached the seats' area after the reflections from these surfaces for the known placement of the screen loudspeakers. This approached was used for the estimation of the proper placement of the sound absorbing materials on the walls and the ceilings of the movie theatres. Acousticians of NIKFI also proposed optimal values of reverberation time for the cinema halls [14,15,20,31,37,44,68,125,178,184]. Their suggestions were fixed in Russian national standards and had been widely used before multi channel surround sound systems became popular.

Various methods for reverberation time calculations in halls and coupled rooms were suggested [105,106,123,124,129,132,145, 160,172,188,191]. They were based on statistical theory and geometrical approach. The main rules for the possibility to use geometrical method were also studied [27,87]. I.Leizer introduced the so-called coefficient of additional sound absorption α_{AD} [38,69,75,88]. The values of RT60 were measured in many multi

purpose halls. They were compared with the results of the calculations that had been done by statistical theory. It was estimated that the calculated values of RT60 in most cases were larger than the measured ones. The reasons of such disagreement were analyzed and the values of α_{AD} were estimated for different octave bands. It was decided to use α_{AD} for RT60 calculation for obtaining more accurate results for the multi purpose halls. Later the same investigations were done for the sport halls [131] and musical studios [180].

An important study on the diffraction of sound was done by G.A.Goldberg and V.M.Lebedev [49,56,57,59,62,83]. They studied the directivity patterns of the sound reflections from the surfaces of the limited area and various constructions. Experiments were done by scale model method with the help of special rotating device. Later the same scale model method was used for the investigation of sound scattering constructions for control rooms based on several digital sequences with good autocorrelation properties [149]. Some acoustic criteria for estimation the sound quality in halls were investigated [6,8,10,11,16,26,93]. Attempts to find the optimal form of 1/3 octave bands frequency curve in musical halls [142,144,151] and to use the statistics of the high-level sound reflections [50-53] may be mentioned. Another researches dealt with the investigation of the seat-deep effect [63], flutter [163], acoustics of small musical classes [161,179] and speech intelligibility in halls [140,164]. L.Makrinenko headed the investigations of echo perception that were done by the method of electoacoustic synthesis of sound fields in a large anechoic chamber [141,153,173,174]. Computer simulation of the room's acoustics was studied by many Russian acousticians [130,134,136,137,154,155,159,167,168, 177,183]. The well-known ray tracing and mirror source methods as well as their modifications and new algorithms had been used.

2.2. Acoustic design

The team from NIKFI has designed many cinema halls all over Russia. There were Moscow cinemas "Rossia", "Pervomajsky", "Perekop", "Varshava", "Volga". Among the movie theatres there were several very large halls, for example "Oktiabr" in Moscow for 2500 seats. There were also designed large multi purpose halls in Kiev (4000 seats), Leningrad ("Oktiabrsky, 4000 seats), Tbilisy (2500 seats), Omsk (1200 seats), Moscow (a large conference hall in the building of the Russian government). The new stage of the drama theatre MHAT in Moscow was also designed by the acousticians from NIKFI. They were active on the acoustic design of studios for motion picture production and other purposes. Studios in Tbilisy, Leningrad, Moscow and other cities were described in the publications. A large studio with variable acoustics was designed for the film studio in Alma-Ata. The results of this successful work were not published. Another very large multipurpose hall for 5600 seats must be noted. It's the Kremlin Palace of Congress in Moscow. Many Russian acousticians participated in the design of this hall, but the team from NIKFI had the leading part. The hall had a low reverberation time, and the system of sound reinforcement protected good speech intelligibility. The descriptions of NIKFI's studies in acoustic design can be found in [2,22,25,32,37,55,68,121,125,156,177,193,194].

Practical studies of the team in VNIITR dealt mainly with acoustic tuning and design of TV, musical, broadcasting studios and control rooms [97,98,169,187]. This work was fulfilled in close cooperation with two design institutes GIPROKINO and GSPI. The results of these works were mostly unpublished. Among the successfully designed rooms with good acoustics there are three musical studios (S=450, 250, 150 m^2) in the house of radio in Kishinev, musical studios in Erevan (S=300 m^2), Barnaul (S=180 m^2), Jakutsk (S=170 m^2), Ulan-Ude (S=150 m^2), Maikop (S=120 m^2), Orel (S=100 m^2), Vladimir (S=80 m^2).

C.Orovue had achieved interesting result in his works in the design of large acoustic shells in the open air [39,46,48]. They are constantly used for concerts of very large choirs that are popular in Estonia and Latvia.

Acoustic team from NIISF designed many theatre and multipurpose halls. The acousticians dealt also with the reconstruction of the existing theatres and concert halls. Many of these rooms were located in the historical buildings. Before the Olympic games in Moscow (1980) this team had made the acoustic design of several large sport halls. Children's musical theatre in Moscow, reconstruction of the drama theatre of the Soviet Army in Moscow, drama theatre in Novgorod, multipurpose hall in Havana (Cuba), reconstruction of the Large Hall of Moscow conservatoire, concert hall in Zelenograd, reconstructions of the Moscow drama theatres Maliy Teatr and MHAT (main stage in historical building) are considered to be successful works. Some of them had been done in cooperation with VNIITR. The descriptions of the rooms and the results of acoustic measurements can be found in [69,99, 100,107,108,114,115,118,120,126,127,131,139,143,152,170,171, 181,182].

2.3. Acoustic measurements

The methods for acoustic measurements on scale models were developed in NIKFI at the middle of 50-th [9,18,35,36]. The scale 1:40 was used mostly. The spark discharge was used as a sound source. There were done measurements in a model of reverberation chamber in order to find proper materials to model the surfaces of the hall and the audience. This method was used for the investigation of acoustics of many halls. Later the same method was used in NIISF. After several attempts with 1:40 scale models [107] it was find necessary to us 1:20 – 1:25 scale models and such scales were used in most investigations [117,126]. The special generators of the spark discharge were developed. It was possible to change in steps the power of the spark discharge and so the maximum of its spectrum may be placed in different frequency bands. There was also developed the omnidirectional transducer for the radiation of the narrow band electrical pulses with the spectrum up to 40 kHz.

Many investigations were done for the optimization of the test signals for acoustic measurements. This problem was studied both theoretically and in experimental way. Although there were studies on stationary signals (frequency bands of noise, multitone, etc) [4,17], the main attention was paid to impulse signals for the measurements of the room's impulse response. Both wide band [73,84,85,102,109,110] and narrow band [113,116,128,133] signals were investigated.

There were suggested many methods to measure diffusion of the sound field. Most of them were based on the usage of directional microphones [3,28,43,74,79,104,138,146]. Correlation methods were proposed as well [19,111]. There were also attempts to find correlation between sound diffusion and time intervals between the sound reflections in the impulse response [64,70,71]. Many papers were published on the reverberation time measurements. The problems of the test signal's choice and the accuracy of the measurements were studied in all the details [76,89,90,112,119, 122,185].

A lot of devices for acoustic measurement had been developed. A powerful analog device was done in VNIITR [61]. It could generate various test signals such as sine pulses with different envelopes, calculate the number of sound reflections, measure the impulse response, etc. The digital methods of measurements based on the usage of computer were developed for the first time by the joint

studies of NIISF and VNIITR [150]. It was possible to measure many acoustic criteria such as D50, C80, LF, EDT, etc.

3. MODERN PERIOD (1992-2001)

After the crash of the USSR the financial situation became very poor in most of the Russian research institutes. The main research centers that studied the problems of room acoustics (NIKFI, NIISF and VNIITR) were not an exception. The government support for the research programs that had taken place for years was stopped. So the only way out for the specialists in room acoustics was to find contracts for the acoustic design of the halls and the studios. The problem was that at that time the new building in Russia was very limited. It could be seen from the references that the number of publication on room acoustics decreased greatly. At the end of 90-th the economical situation in the country became much better. The designs of the new theatre and concert hall as well as the reconstruction of the existing ones started. Russian acousticians were active in this job. A new acoustic laboratory was organized in 1998 at the Moscow Research & Design Institute for Culture, Leisure, Sports & Public Health Constructions (MNIIP). It was directed by V.Soukhov who passed to MNIIP from NIISF where he had been the head of the laboratory of architectural acoustics since the death of L.Makrinenko in 1997.

Only one research program at that period can be mentioned. It deals with the investigations on the acoustics of historical buildings. Many old theaters, churches, cathedrals and concert halls were studied [195-197,199,201,203,205, 207-210,214,219]. Very few other researches that were published dealt with investigations on the sound decay in small rooms [198], the usage of RASTI's method for the Russian language [200] and calculations of the sound pressure inside some types of closed volumes [220].

Important studies on the acoustic design of a new sister stage of the Bolshoj Theatre in Moscow were done. The primary design of this hall for 900 seats was done by a group of acousticians headed by L.Makrinenko [207,208]. This hall is still being built and some changes to the primary design are proposed [215]. A new opera house "Novaja Opera" was open in 1998 in Moscow. The acoustic design of this 790 seats opera house was also headed by L.Makrinenko with the participation of M.Lannie and V.Soukhov [208]. This work was very successful and the hall has nice acoustics. Another two musical theatres are being built in Moscow now. They are (1) the State Ballet theatre with two halls for 1000 and 300 seats and (2) the small opera hall for 250 seats in Galina Vishnevskaja's theatre-studio [208]. Among the finished halls may be noted the musical theatre for 1200 seats in Rostov-on-Don [216], small hall for 280 seats in the conservatoire of Nijniy Novgorod and Large concert hall for 1000 seats of Tatarstan in Kazan [213].

Since 1992 acoustic design of cinemas has been dealt mainly with the reconstruction of the existing halls for the installation of multi channel sound systems (Dolby digital, for example). Acoustic teams in NIKFI and MNIIP did many such projects, but their results are not published. Some data on the subject can be found in the paper M.Lannie, N.Soukchov "Acoustic renovation of the cinema halls in Russia" has been recently accepted for the publication as preprint of the 112-th AES Convention.

A lot of works on acoustic design of theatres, concert halls and sport halls are still not published. Some of the most interesting projects will be mentioned. The acousticians in NIISF (L.Borisov and Ch.Schirjetsky) are responsible for the design of a new large complex "Krasnii Holmi" (Red Hills) that is being built in Moscow. The complex includes two large concert halls. Ch.Schirjetsky designed cinemas "Kosmos" and "Orbita" in Moscow. The team from MNIIP (V.Soukhov and M.Lannie) made acoustic design of drama theatre named after Meerhold in Moscow; a musical theatre for 400 seats and recording studio in Uralsk; State Opera and Ballet Theatre named after Abai for 800 seats in Alma-Ata, Kazahstan (full reconstruction of the existing hall); a drama theatre in Vladikavraz; philharmonic halls in Perm and Barnaul (together with P.Kravchun who was responsible for the design and technology of organs); a student's theatre for 500 seats in Surgut; a concert hall for 700 seats for the musical school in Novokosino, Moscow; a drama theatre for 300 seats in Petrozavodsk; a puppet-show theatre in Ulianovsk; sport hall "Vitiaz" for 5000 seats in Podolsk.

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APPENDIX 1. REMARKS TO THE REFERENCES

In 1949 five acousticians published the tutorial [1] with a very detailed bibliography of the Russian investigations on architectural acoustics. It included 421 references in the field of room acoustics, sound reinforcement, noise control, sound absorbing materials and acoustic measurements. Among these references were also many not published studies from the reports of several organizations. The authors of [1] wrote that they tried to include all the papers on the subject they were aware of.

The presented in this tutorial bibliography has different bases. On one hand the authors tried to include all the main studies that had been done by the Russian specialists in room acoustics. On the other hand they didn't want the list of the references to be too long. So the following decision was chosen. The list includes only research studies on room acoustics, acoustic design and acoustic measurements in rooms. The papers on sound reinforcement, sound insulation and noise control and were omitted. There were excluded the published PhD thesis, Russian national standards on acoustic, recommendations on acoustic design and all students text books and popular books on the subject. The exception was only for two students' text books [29, 58] that were most popular and were translated into foreign languages. There were also omitted abstracts and papers that had been published in the proceedings of various conferences where the size of the publications was strictly limited to 1-4 pages. As far as the authors know most of the publications in the conferences proceedings were based on the studies that were presented in the list of the references. The only exception was the recently published proceedings of the sessions of the Russian Acoustic Society. This edition had no strict limitations on the papers' size and was published in English as well.

The authors included all the papers that were based on the mentioned principals. They tried to do it carefully and hoped that most of the published Russian studies on architectural acoustics are presented. Of cause it is rather difficult to give the full bibliography on the investigations done during 50 years, and some papers may be missed. So the authors will be grateful to their colleagues for any additions and extra information to the bibliography.

Some remarks on the Russian periodical editions where publications on room acoustics can be found seem to be useful. The most well known journal is Akusticheskiy Zurnal (Acoustical journal) that has been issued since 1955 by the Russian Academy of Science. This journal was translated into English from the very beginning. Up to 1993 the English edition was named "Soviet Physics Acoustics", and form 1993 it has been named "Acoustic Physics (Russia)".

The other journal that is still being published is Technika Kino i Televidenia (Techniques of motion picture and television). This Russian language journal was founded in 1957. It covers a wide field of themes and includes a block of research papers.

The other periodic editions are the proceedings of several institutions. From the beginning of 90-th all these proceedings were stopped or were not published regularly. It is necessary to mention them, because most of the Russian researches on room acoustics were published on their pages. 1. Proc. of NIKFI. They had been published on regular basis since 30-th. 2. Proc. of VNIITR. These proceedings had been published on annual bases since 40-th. 3. Stzenicheskaia technika i technologia (Technique and technology of the theatre stage). This edition was published (6 books every year) by the Moscow institute GIPROTEATR responsible for the design of theatres all over Russia. 4. Proc. of NIISF This edition had been published on annual bases since 60-th. 5. Voprosi radioelectronicy, TRPA (Problems of radioelectronocs, issue "Technique of radio broadcasting and acoustics"). This journal (2-3 books every year) was in fact the proceeding of the Research Institute of Broadcasting and Acoustics (IRPA), S.Petersburg. 6. Trudi LIKI (Proceedings of the Leningrad Institute of Motion Picture Engineers; were published on annual bases).