Session 5aAA

Architectural Acoustics: Building Acoustics II: Reverberation, Absorption, and Scattering

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Chair's Introduction—7:55

Contributed Papers

8:00

5aAA1. The anecoicity phenomenon in a live room. Higini Arau (Estudi Acustica. H. Arau. Trav. de Dalt, 118 Barcelona 08024, Spain)

The radius of reverberation must be obtained by iteration of the following equation: $Q/r^2=312(T/V)e^{-0.04r/T}$. The phenomena of the anecoicity are noticed when the radius of the reverberation does not exist because the sound direct curve never intercepts the sound reverberant curve; because of that the sound reverberant field is not a constant, as it was assumed in the classical formulation. In this case it is known [M. Barron and L. J. Lee, J. Acoust. Soc. Am. **84**, 618–628 (1988)] that the reverberant function is dependent on the distance through an exponential function. Therefore a minimum distance of reverberation will exist among both curves, which are very near. This distance is obtained by finding the minimum of the function: $e^{0.04r/T}/r^2=312T/QV$. This minimum distance is $r_{\min}=50T$. Also, a minimum directivity factor of the source is determined, including $r_{\min}$: $Q_m=105\,561.5209T^3/V$. This $Q[m]$ expresses the minimum directivity factor, for a determinated T and V, that must have the sound source because the sound direct field never intercepts the reverberant sound field. With this it will be possible to establish a direct dialog source-receptor without the liveness of the room being damaged.

8:20

5aAA2. Orthogonal acoustical factors of sound fields in a bamboo forest. Hiroyuki Sakai (Grad. School of Sci. and Technol., Kobe Univ., Rokkodai, Nada, Kobe, 657-8501, Japan), Shozo Shibata (Kyoto Univ., Sakyo, Kyoto, 606-8224 Japan), and Yoichi Ando (Kobe Univ., Rokkodai, Nada, Kobe, 657-8501 Japan)

In order to discuss acoustical quality of sound fields in a bamboo forest, acoustical measurements were conducted for orthogonal acoustical factors of a sound field. Results at a distance of 40 m from the source show that the IACC was 0.16 at 2 kHz. This value is smaller than that in the forest previously investigated [Sakai, Sato, and Ando, J. Acoust. Soc. Am. **104**, 1491–1497 (1998)]. The measured subsequent reverberation time T_{sub} was about 1.5 s in the frequency range above 1 kHz. For a certain music source with a higher frequency component, therefore, it is found that sound fields in the bamboo forest have excellent acoustic properties.

8:40

5aAA3. A refined room acoustical simulation algorithm based on free path distribution. Oliver Schmitz (Inst. of Tech. Acoust., Tech. Univ. Aachen, Templergraben 55, 52056 Aachen, Germany, osc@akustik.rwth-aachen.de)

Eyring's or Sabine's formula gives good results in rooms with a diffuse field. However, when long, flat, or coupled rooms, for example, are investigated, these formulas do not describe the decay correctly. The error has its reason in the assumption of an exponential decay with just one exponential coefficient calculated from the mean free path length and an averaged absorption coefficient. A new approach to calculate decay curves and reverberation time, already introduced by Vorländer [''A fast room acoustical algorithm based on free path distribution'' ICA 98] has been further refined. This method uses statistical results obtained by a short ray-tracing simulation. Free path length and absorption coefficient are statistically recorded for each reflection during this simulation. The recorded data represent the geometry of the room under investigation. In the next step several processes, each defined by an exponential function, are generated using this information, which are superposed to give a better approximation for the decay curve of the room. Some additional steps must be introduced to these processes to give reasonable results. This lecture will present the refined algorithm and some results.

9:00

5aAA4. Performing room surfaces' effects on the acoustical condition distributions. Aye Erdem Aknesil (Yildiz Tech. Univ., Faculty of Architecture, Yildiz-Besikta, Istanbul, Turkey)

To obtain suitable acoustic conditions for the important rooms from the room acoustics point of view, some parameters have to be evaluated. For example, reaching the acceptable reverberation time limits, not the place of surfaces but the total absorbtion, has an important role according to the size of surfaces and absorbability. On the other hand, while designing the first reflections or avoiding the constitution of acoustical defects like echo, the place of the suitable surfaces is important. When considering the importance of the distribution of acoustical conditions, the question is posed of how the surface affects this matter. In line with this observation, the aim of this study is to find the effects of the surfaces according their ratios.

9:20

5aAA5. Reverberation in rectangular long enclosures with diffusely reflecting boundaries. Jian Kang (The Martin Ctr., Cambridge Univ., 6 Chaucer Rd., Cambridge CB2 2EB, UK, jk10021@hermes.cam.ac.uk)

Based on the technique of radiosity, a computer model has been developed for calculating acoustic indices in rectangular enclosures with diffusely reflecting boundaries. The model divides every boundary into a number of patches and replaces patches and receivers with nodes in a network. The energy moving between nodes depends on the form factor between pairs of patches. For a cube, there is good agreement between the model result and classical theories, which can be regarded as a validation of the model. Computations for long enclosures show that (1) with the increase of source–receiver distance the RT30 increases continuously and the early decay time (EDT) increases rapidly until it reaches maximum and then decreases slowly—correspondingly, the decay curves are concave in the near field and then become convex. (2) Air absorption has greater effect on both reverberation and sound attenuation along the length than that with geometrically reflecting boundaries [J. Kang, Acust./acta acust. **82**, 509–516 (1996)]. (3) With a constant cross-sectional size, reverberation time reaches a maximum as the aspect ratio tends to 1. (4) With a given amount of absorption, reverberation can vary considerably with various absorption distributions in a cross section. [Work supported by Lloyd Foundation.]

9:40

5aAA6. The genetic algorithms for the optimization of distributed loudspeaker systems. Corinne Fillol and Claude P. Legros (LAUTM, Universite Toulouse le Mirail, 31058 Toulouse Cedex, France, legros@univ-tlse2.fr)

In reverberant and highly noisy environments, public address systems are often used in order to improve the speech intelligibility. Nevertheless, a number of common problems are generally encountered with such installations. Too many distributed loudspeaker systems suffer an inappropriate utilization of loudspeakers which leads to an excessive excitation of reverberant field and a poor audience coverage decreasing the intelligibility. Two rules of thumb have been well formulated to optimize uniformity of audience coverage, but both of them did not take in account the emission of the loudspeaker in its acoustic environment. Too many sound systems, in factories and public spaces, are therefore ineffective and do not respect the safety standards. Nowadays, it is possible to predict the acoustic performance and to simulate the radiation of a sound system in space by the means of geometric approach. The utilization of such a program with natural algorithms allows the optimization of the positioning and the number of loudspeakers by considering the acoustic characteristics of the room and sources. The performance of this method is applied in the case of choosing a best configuration from 16 possible loudspeaker locations in a classroom in order to obtain an optimum speech intelligibility and allow a smaller cost of renovation.

10:00–10:20 Break

10:20

5aAA7. A Helmholtz resonator with elongated orifice. Rolf T. Randeberg, Ulf R. Kristiansen, and Tor E. Vigran (Acoust. Group, Norwegian Univ. of Sci. and Technol., N-7034 Trondheim, Norway, randeber@tele.ntnu.no)

For panel absorbers there is an increasing trend toward a design not utilizing fibrous components. For the distributed Helmholtz type of resonator absorbers, the challenge is to increase the natural losses, making the absorbers reasonably broadbanded. In this paper a new type of distributed resonators is investigated. Using a double-plate construction, the resonator necks have been substantially elongated in the lateral direction, while their widths have been kept small. Thus the viscous losses in the resonator necks have been increased compared to traditional resonators. Measurements are compared with a theoretical model using analytic solutions for the slit impedances, the end corrections, and the resistance of the inner and outer surfaces. For the volume between the plates, a finite-difference approach is used. The results show a high dependency on the plate separation, and to attain high absorption over a broad frequency range, this separation should be on the order of one boundary layer.

10:40

5aAA8. A seamless absorbing ceiling with a smooth surface: Álvaro. Daniel E. Commins (commins acoustics workshop, 15 rue Laurence, F-75020 Paris, France and 350 Fifth Ave., New York, NY 10118, comminsacoustics@compuserve.com) and Frank H. Wilhelmi (Wilhelmi Werke A. G., D-35633 Lahnau, Germany)

The use of absorbing ceilings is generalized. Contemporary architecture, in many cases, does not relish the use of ''classical'' absorbing ceilings of the perforated or slit type. Some manufacturers have developed smooth absorbing ceilings that can cover large areas without seams. Until today, the finish of these ceilings was unacceptable wherever a perfectly smooth surface was required. Improving on existing technology has led to a new type of ceiling: its surface is quite similar to a stucco or plasterboard finish, but its absorption coefficient is of the order of 0.5 over the full frequency range. The quality of the finished surface depends on the material itself and the quality of construction. Examples will be shown. In addition, this new type of ceiling has been mixed with other materials such as stucco, wood, fiberglass, and even loudspeakers. It has been shown in a full-size test model that it is possible to apply the same finish to all these materials, thus making the transition between the various components invisible. The absorptive and reflective parts of a wall or ceiling become undistinguishable. This ceiling has been named Álvaro since it was developed with the active input of Architect Álvaro Siza.

11:00

5aAA9. Effect of plate vibration on sound absorption of the microperforated elastic plate. Manabu Tanaka (Bldg. Res. Corp., Osaka, 5650873 Japan, czu14202@nifty.ne.jp) and Daiji Takahashi (Kyoto Univ., Kyoto, 6068317 Japan)

Perforated plates have long been used as sound absorbers, and many studies have been done on their acoustic characteristics. In these studies, the effect of plate vibration caused by the incident sound wave is neglected. This is reasonable for the perforated plate of ordinal design [D. Takahashi, Appl. Acoust. **51** (1997)]. However, if the ratio of perforation decreases, e.g., in case of the micro-perforated plate, the effect of plate vibration is considered to be distinct, because the flow resistance of the plate is relatively large in this case. In this study, a new theoretical model for predicting the acoustic characteristics of the micro-perforated elastic plate (MPEP) is presented. This model includes the effect of plate vibration caused by the pressure difference between both surfaces of the plate. Numerical experiments are also carried out with this model. From the results, it may be said that the plate vibration occurs when the surface porosity of the perforated plate is roughly under 1%. This model can be applied to the perforated plates of any flow resistance, i.e., from the ordinarily perforated plate to nonperforated plate throughout.

11:20

5aAA10. Simplified calculus to estimate the acoustical absorption of nonplanar materials. Jaime Pfretzschner, Francisco Simon, Rosa M. Rodriguez, and Carlos de la Colina (Inst. de Acustica (CSIC), Serrano 144, 28006 Madrid, Spain)

The absorption curve, in function of the frequency, in hard-backed layers of granular materials, shows undesirable series of maxima and minima related to the layer deep. In order to increase the efficiency of these absorbing materials, it is necessary to smooth their frequency response curve. It is obvious that one of the easiest solutions consists of modifying the layer surface with selected profiles (e.g., wedges). For these situations, a simplified method of analytical calculus for the valuation of the absorption, in function of the frequency, has been developed. The validity of the theoretical approximations has been checked against experimental measurements in different test samples by means of a standing wave tube. Additionally, the application of this study to the design of absorbent acoustic noise screens, against traffic noise, made with recycled rubber crumbs of tires, is also presented. [Work supported by a LIFE project.]

11:40

5aAA11. Reflection and diffraction in room-acoustic modeling. Jan Baan and Diemer de Vries (Lab. of Acoust. Imaging and Sound Control, Delft Univ. of Technol., Delft, The Netherlands)

Many programs for room-acoustic modeling are based on the mirror image source concept. This way, only specular reflections are taken into account such that the resulting wave field is incomplete. Nonspecular reflections, or diffraction phenomena, can be added using an algorithm based on Pierce's theory. Then, the true wave field is significantly better approximated. However, comparison of both results reveals that, averaged over time and space, the energy is equal in both cases: the added diffraction field so strongly interferes with (i.e., is so strongly correlated with) the specular reflections that no energy is added. This intuitively surprising