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The effects of light equipment on the acoustic characteristics of a TV studio

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ABSTRACT

The characteristics of light equipment were investigated to understand their acoustic properties and effects in a television (TV) studio. The absorption coefficients were measured in a reverberation chamber with representative spotlights of 1 kW and 2 kW. Based on the absorption coefficients, laboratory tests using a 1:10 scale model of the test specimens were designed. The purpose of the experiment was to identify the absorption and scattering characteristics, including the coverage density, angle, and the presence/absence of barn doors. The results showed that the averaged absorption coefficients varied from 0.04 to 0.13, and the averaged scattering coefficients ranged from 0.35 to 0.81 as the coverage density varied from 5 to 16%, respectively. When the height position of the light was varied from 9 m to 3.5 m in the TV studio, it was found that the sound strength increased to 0.71 dB, and the clarity (C50) decreased to 0.30 dB. At a low height of 3.5 m, the reverberation time (T20) and the early decay time (EDT) increased for frequencies below 500 Hz and decreased for frequencies above 500 Hz. The use of light equipment increased the sound strength; however, the variation in both T20 and C50 was only slight. The standard deviation of the EDT and C50 in the space decreased by 16% and 43%, respectively.

1. Introduction

The acoustic properties of a space are affected by diverse factors, including the volume, the number of musicians on a stage, the size of the audience, wall and ceiling materials, seats, and stage elements. The most fundamental approach for the description of room characteristics was conducted by Sabine [1]. In his formula, there are two critical elements: the volume and absorption area in an enclosure, and the relationship between the random-incidence absorption coefficient and the reverberation time (RT). Musicians, musical instruments on the stage, seats, and the audience have distinct absorptive characteristics that influence the acoustic properties of reverberation and sound pressure level [2–5]. Properly used wall materials reduce acoustic glare and coloration [6]. The open ceiling in a multipurpose hall equipped with a steel truss, ducts, catwalks, and ceiling surfaces presented a range of absorption coefficients from 0.19 to 0.61 [7]. Variable stage elements, such as fly curtains, side curtains, cycloramas, and stage sets, were found to be important factors affecting the RT in a stage house and the seating area [8].

In previous studies, most factors affecting room properties in various manners were considered to be fixed in space during a performance. In performing spaces, such as multi-purpose halls, opera houses, and drama theaters, light equipment is installed over a stage, on the side walls, above the ceiling of the audience area, and occasionally, on the stage floor. Most halls use lights to a greater or lesser extent; however, the acoustic information and the effect of light equipment on a hall has not been studied in previous works. Instead, it has been limited to an analysis regarding the effect of illumination from a visual aspect, and in terms of fulfilling certain aesthetic functions from a visual perspective. However, light equipment also works like fixed materials as it affects sound properties during the performance in a hall, despite significant variations in their position and regardless of the coverage density of various pieces of light equipment. The importance of using both the scattering and absorption coefficient of a material or a surface in acoustical computer simulations for a room is well known [9]. In various performing spaces, a large number of light equipment and related devices are installed on the ceiling, the side walls, and even on the ceiling of the audience area. Considering its occupation density and its variation in height and position, light equipment should affect the sound field of a space. However, there is a lack of

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measured data and studies on the influence of light equipment. This is a significant omission because light equipment may change the characteristics of a sound field, causing variation in the auditory environment.

The purpose of this study is to investigate both the acoustic properties of light equipment and its effect on the sound field in a television (TV) studio. The acoustic values of random-incidence absorption and scattering coefficients of light equipment obtained through diverse measurements can be used for the prediction of acoustic properties; the results of in situ measurements may be used for room design, by considering the light equipment effect. In a TV studio, various types of spotlights and floodlights are used. Among them, the most commonly used cylindrical spotlights of 1 kW and 2 kW were chosen for analysis, and the absorption coefficients were measured in a reverberation chamber. Based on the absorption coefficients, various absorption and scattering coefficients at different angles and with/without barn doors, which control the spread of a light beam, were measured using a 1:10 scale model. Moreover, in situ measurements were obtained in a TV studio to determine the influence of light equipment in a realistic situation.

2. Measurements of acoustical properties of lights

2.1. Absorption coefficients

The random-incidence absorption coefficients of the light equipment were measured in real and 1:10 scale-model reverberation chambers with a volume of 325 m^3 and 0.253 m^3, respectively, according to ISO 354 [10]. Two omnidirectional loudspeakers (B&K Type 4296) were used, and impulse responses were recorded three times at six receiver positions, using 1/2-in. microphones (GRAS Type 26CA). The sound source of the maximum length sequence (MLS) signal was used in the measurement. A total of 36 impulse responses were obtained for the reverberation time (RT) from 1/3 octave bands, which ranged from 100 Hz to 5 kHz. The RTs in the 1/3 octave bands were averaged over two source and six receiver positions in three repeated tests.

In the case of the 1:10 scale-model reverberation chamber, high-voltage electric spark sources at three positions were used, and impulse responses were recorded three times at four receiver positions using 1/8-in. microphones (B&K Type 4138) from 1 to 50 kHz. The basic principle of absorption is to be calculated with and without the use of test samples. The absorption coefficients for frequencies in the range of 125 Hz to 4 kHz were calculated as octave bands, which were derived from averaging the center frequencies of the 1/3 octave bands that ranged from 100 Hz to 5 kHz. Environmental conditions, such as temperature and relative humidity, were measured for correction of air absorption, in accordance with ISO 9613-1. The measurement environment was maintained at temperatures of 18 $\pm$ 0.2 °C and 23 $\pm$ 0.7 °C, and at humidity levels of 44 $\pm$ 0.5% and 32 $\pm$ 1%, respectively.

The light equipment was placed on a 3 $\times$ 4 m^2 floor without an edge screen, as shown in Fig. 1. The 1-kW light equipment has a diameter of 250 mm and a length of 300 mm, and the 2-kW light equipment has a diameter of 300 mm and a length of 350 mm. The coverage density was calculated based on the area that covered the floor. The 1-kW measurements started with eight lights and a coverage density of 0.075 m^2/light. The 2-kW measurements started with six lights, with a coverage density of 0.105 m^2/light. The coverage density of the 1 and 2 kW lights was varied from 5 to 15% and from 5 to 16%, respectively.

Light equipment consists of metal, lenses, knobs, and lamps, which are mostly reflective materials. Thus, acrylic plates were chosen as materials for the fabrication of the scale-model specimens, which were fashioned into cylinders with a 1:10 scale and a thickness of 1 mm, based on the size of the real lights.

In order to match the absorption power absorbed by light equipment of the real to the scale model sample in each band, an acrylic plate at a scale of 1/10 of an empty cylindrical bucket was fabricated. It was then shaped as coins made of acrylic plate with a thickness of 5 mm, and was filled in a cylindrical bucket. The gap with coin-shaped acrylic plates was adjusted inside the bucket repeatedly to match the absorption power of a real reverberation chamber. This adjustment was made because if the gap widens, the low-frequency resonance increases; if the gap narrows, the frequency resonance becomes decreases. With proper adjustment of the gap width and the number of coin-shaped acrylic plates, it was possible for the specimen to match the real light with less than a 0.03 absorption power in each octave band, as shown in Table 1. In order to extend the investigation of the acoustic characteristics, more diverse situations with scale models were considered, which are difficult to be realized in a real reverberation chamber. In the real measurement, only the horizontal situation was measured; however, in the 1:10 scale-model, horizontal, vertical, and vertical-with-barn-doors cases were also examined, as shown in Fig. 2.

The angle of the light equipment can be varied according to the objects, such as the movement of an actor, set design, and scenery. In a real situation, light is radiated at various angles; however, in the scale-model measurement, only two cases were included, namely the horizontal and vertical positions. The barn doors are mostly used to adjust the amount and direction of the luminance; nevertheless, certain light equipment, such as the ellipsoidal reflector spotlight and the parabolic aluminized reflector light, have internal shutters or narrower lenses instead of barn doors. Thus, both with and without barn doors cases were included in the present study. The barn doors were also made of acrylic plates at a scale of 1:10 to the real size, with a thickness of 1 mm. The size of the 1-kW and 2-kW barn doors was almost the same; therefore, in this study, the same surface area of 0.022 m^2/light was used.

2.2. Scattering coefficients

The measurements of the random-incidence scattering coefficient were conducted with the same sample used for absorption test. A 1:10 reverberation chamber was used in the measurement of the scale-model absorption coefficients, in accordance with ISO 17497-1 [11]. The chamber included a moving electric turntable with a circular plate of a 420-mm diameter. Two tweeter loudspeakers were located in the corner of the reverberation chamber. Impulse responses were recorded from 88 different directions in a rotation cycle using a multi-MLS signal. The signals were generated at two source positions, and were received at four receiver positions using a 1/8-in. omnidirectional microphone. The principle of a measurement method is to extract the specular energy from the reflected pulse. This can be accomplished through the synchronized averaging of the impulse response obtained for different sample orientations. Through the synchronized averaging of the pressure impulse responses, the specular components add up in phase, whereas the scattered sound interferes destructively. In order to measure the scattering coefficients, the reverberation time was calculated under four different conditions: the turntable is fixed or rotating, with and without the specimen. The impulse responses were measured with and without a specimen on the non-rotating turntable, and yielded a reverberation of T_1 and T_2, respectively. The results of the measurement with a continuously rotating turntable with and without the specimen yield a reverberation time of T_3 and T_4, respectively. For the calculation of the scattering coefficients of the light equipment, the floor areas occupied by the lights affected the absolute values, because the