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MODEL STUDIES IN ACOUSTICS

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THE USE OF A MODEL AS A DIAGNOSTIC TOOL

H.D. Harwood

INTRODUCTION

The science of room acoustics is not an exact one and therefore it is not possible completely to predict the properties of a music studio or concert hall from theoretical considerations. Owing to varying design factors, such as the use of differing construction materials and methods, no two studios are, in general, the same. Their acoustic treatment is therefore individual and may be costly, particularly if substantial alterations are necessary, after nominal completion, in order to achieve the required acoustic quality.

This paper discusses the general principles and some of the problems associated with a method of predicting the acoustic properties of a studio or concert hall by means of an acoustic model. It is shown that not only can the more physical attributes, such as the reverberation time, be measured, but it is possible to reproduce programmes in the model and listen in such a way that a subjective assessment of the sound quality of the full size studio can also be made.

HISTORY

The history of acoustic modelling dates back to at least 1926 when both Schlieren spark methods and ripple tank methods were employed at the National Physical Laboratory. Later, at the University of Munich Spandock in 1934 described the basic principles underlying modelling and measured such parameters as reverberation times, reflections, etc. with the somewhat crude equipment available to him. Within the last few years the equipment has improved radically and the study of modelling is now general.

BASIC PRINCIPLES

If a studio model is made with a scale factor of 1/K the following conditions will apply: (a) the time between reflections will be reduced in the same ratio 1/K, (b) for similarity in wave acoustic behaviour the sound wavelength must also be reduced in the ratio 1/K, and therefore the frequencies must be increased in the ratio K/1, (c) the air absorption must be increased by a ratio K/1 over that applying at normal frequencies since the path lengths are reduced by 1/K, (d) if the acoustic impedances of the surfaces of the model over the scaled up frequency range are made equal to those of the corresponding surfaces in the full-size studio over the normal frequency range, it follows that the reverberation time will be reduced in the ratio 1/K.

Thus a stereo recording of programme material made in free field surroundings, i.e. free of reverberation, is reproduced in the model at a tape speed K times that used for the original recording The output from a pair of microphones in the model is recorded at this high tape speed and subsequently reproduced at normal speed for subjective assessment. In this way the acoustics of the model should correspond to those of the full-size studio and can be judged accordingly. Similarly the variation in reverberation time with frequency can be measured objectively in the model to verify that the optimum values have been achieved for the particular use to which the studio will be put.

PRACTICAL DIFFICULTIES

The theory behind acoustic modelling is simple; there are however considerable practical difficulties in achieving a worthwhile result. The difficulties lie in the field of instrumentation and are as follows:— The scale factor must be at least 1/8 to produce a reasonable size model and this scale requires a frequency band extending from 400 Hz to 100 kHz. It follows that the tape recorder, microphones and loudspeakers must also be capable of covering this frequency range not only with a good signal-to-noise ratio, but also in the latter two cases with the desired directional properties. This paper briefly describes some of the modifications which were necessary to achieve this end, together with means for drying the model and the enclosed air rapidly to a value of about 3% RH. In addition it is necessary to find absorbers which possess, at the new scale of frequencies, the same absorption properties as the original materials at audio frequencies. The measurement of these properties demands the construction of a model reverberation room.

TAPE RECORDER

The tape recorder has to cover both the audio frequency range 50 Hz to 12 kHz and the corresponding scaled frequencies. The most easily available recorder which will do this is of the instrumentation type which covers a binary range of tape speeds. For economic reasons therefore the scale ratio K was fixed at 8, rather than say 10 which had certain attractions and the scaled frequency range therefore covered 400 Hz to 100 kHz. Now the signal-to-noise ratio for these machines was not guaranteed to be better than 30 dB, a quite inadequate figure for subjective work. To improve on this figure special heads were obtained so that the four tracks, a stereo pair each for instantaneous replay and record, employed one inch wide tape. The heads had also to be screened magnetically much more carefully than was standard practice and individual wipe track facilities added. With the addition of pre-emphasis and de-emphasis a weighted signal-to-noise ratio of 52 dB was finally achieved. Even so, this instrument proved to be the noisiest link in the chain.

MICROPHONES

The only commercial microphone capable of the extensive frequency range needed for this work at the time it commenced was a 6·5 mm diameter capacitor type. With the cathode follower type of head amplifier provided by the makers the equivalent noise level was excessive and would have resulted in a very poor signal-to-noise ratio. A new head amplifier was therefore designed using a field effect transistor and this produced an improvement in the noise figure of 15 dB. In order to obtain directional information about the model a stereo pair of spaced microphones was used. It should be noted that a 6·5 mm microphone is too large in diameter by a factor of two compared with the microphones normally used in studios but no other choice was available. It does however mean that the ratio of direct to random sound will be different at high frequencies to that from normal studios.

LOUDSPEAKERS

Various suggestions have been made as the directional properties of the loudspeakers, for example, that they should imitate the human voice, or at the other extreme, a complete orchestra. In our case we first wished to perform a proving experiment in order to check that the sound quality obtained from the model was realistic. To do this it was proposed to model an existing studio, play in it a tape of non-reverberant music and compare the acoustic quality from the studio with that derived from the model; a real check on the modelling technique would thus be made. To do this it would be necessary to reproduce the programme in the studio on monitoring loudspeakers and it was therefore decided to make the loudspeakers for the model on similar lines. However, the only high frequency units which were commercially available to cover the range up to 100 kHz were electrostatic devices about 25 mm in diameter. As the wavelength of sound is about 3mm at this frequency it meant that the units were highly directional and it was decided to mount a number of them on the surface of a hemisphere in order to get a reasonably wide angle of radiation. Each unit is not very efficient and in order to get a good signal-to-noise ratio 45 were employed covering an included angle of about 120°. The lowest frequency at which the units could handle full modulation was about 15 kHz.

The middle frequency units covered the frequency range 3 kHz to 20 kHz. They consisted of a pair of electrodynamic units designed as tweeters and used hemispherical Melinix diaphragms. As such they were remarkably free from colouration and possessed good directional properties. The low frequency units were 110 mm in diameter and covered the frequency range 400 Hz to 3 kHz; they were specially made for the purpose from a thermoplastic material having a high internal damping. Even so it was found necessary to add a coating of damping material to get the required sound quality. It should be noted that the requirements for the model loudspeakers are much more stringent as regards resonances than are those of normal monitoring loudspeakers. For example, a resonance at 8 kHz with a decay of 10 ms would be inaudible in a normal loudspeaker. However, in a model when transposed downwards by a factor of 8 to 1 the resonance would be at 1 kHz, right within the aurally sensitive band, and would have a decay of 80 ms. Such resonances are therefore much more easily audible than in normal loudspeakers and this has been found to be the weakest link in the chain from the subjective angle.

AIR ABSORPTION

Sound attenuation in air exceeds that observed for classical gases owing to molecular relaxation absorption in oxygen which varies as a function of humidity. By drying the air to about 3% relative humidity the sound attenuation is approximately correct. Reduction of humidity in models by means of silica gel has been practised in Germany but periods of several weeks to obtain the desired values have been reported. In the present case an artificial zeolite has been employed instead and the drying time has been reduced to half a day in the first instance and about 15 minutes for subsequent occasions.

ABSORPTION COEFFICIENTS OF MATERIALS

Absorption coefficients of materials in the model should be the same as those in the full-scale room at the appropriate frequencies. The coefficients were measured in a small reverberation room which was a 1/8th scale model of a room to ISO standards. Several attempts were made to construct a room before the results met the required standard. The final room was made of 12 mm steel with semi-polished walls and a transparent 12 mm Perspex top so that the microphone positions could be seen. Diffusers were hung from the top in accordance with ISO recommendations. The reverberation time in the empty room exceeded the minimum ISO values at all frequencies when the relative humidity was reduced to 3% by the methods outlined above.

Samples were predried in a separate chamber before being introduced into the reverberation room.

A considerable number of tests were made on various materials to imitate the absorbers found in the real studio. In modelling those care was taken to employ similar materials where possible, i.e. carpet was successfully modelled by a particular type of velvet, parquet flooring by a rigid plastic faced laminate etc. More difficult to model was the studio roof which was known to resonate at a low frequency. In the end the absorption characteristics were simulated by a p.v.c. lined paper backed by an air space which in turn was damped by a suitable absorbent.

REVERBERATION-FREE MUSIC

In order to assess subjectively the acoustics of the model it is desirable to employ reverberation-free (dry) music. Such a programme was recorded in stereo from a small orchestra performing in a large free field room. In addition to several orchestral items, various staccato chords were played to help in the assessment of the reverberation.

RESULTS

(a) Reverberation Time The reverberation curve of the real studio is not as flat as usually obtained. However it was with some degree of satisfaction that the corresponding curve for the model was measured and agreed within ± 10% of that for the real studio. This difference would not be expected to be audible.

(b) Subjective Assessment of Sound Quality Recordings were made in the studio, and in the model, of the dry music when played through two spaced loudspeakers and re-recorded using a pair of spaced omnidirectional microphones. This was done for two types of monitoring loudspeaker in the studio to observe the effects of loudspeaker design on the sound quality.

The recordings have been compared and assessed by many specialists from within the BBC. It is felt that in so far as the quality of the loudspeakers affects the judgement, those in the model lie somewhere between the two types of monitoring loudspeaker used in the studio. In addition, however, the acoustic properties of the studio are readily apparent and it has been shown, for example that the effect of the addition of an orchestra could be easily discerned, not so much as a change in reverberation time, which is to be expected, but as a definite change in tonal quality, a factor which could neither be predicted nor measured. It is a facility such as this which underlines the usefulness of the modelling technique and renders it indispensable in any large scale construction.

The technique and instrumentation having thus been proved, work has commenced in its application to the study of the faults of the main studio itself. A detailed questionnaire has been sent out to a number of the users and the results are being analysed statistically.