15

SOUND ABSORPTION CHARACTERISTICS OF INDIAN MATERIALS—PART I

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ABSTRACT. A proper understanding of the acoustical properties of materials is becoming increasingly important because of the wide variety of important applications in which they are finding use. A simple and useful method is presented for the investigation on the acoustic properties of some of the materials available in India. The effect of various angles of incidence for different audio frequencies (64 c.p.s.—8192 c.p.s.) on the absorption coefficients of the materials have been studied. The paper also outlines the method giving description of the equipment and measurements on the characteristics of the chamber and the source of sound employed for the purpose.

INTRODUCTION

Since a long time the reverberation has been found to be the most important acoustical defect of a room and as early as 1835 Reid suggested that this defect is minimised if the surrounding space could be more absorbent, that is by making the surfaces of the wall rough and irregular.

Roger Smith in his 'Acoustics of Public Buildings' remarked,' In empty houses a great reverberation is perceptible which diminishes as the floors are covered with carpets and the rooms filled with furniture.

Johnstone Stoney (1885) tested a room having its walls papered over a lining of canvas which was stretched in front of a framework fixed on the wall and from his experiment he inferred that public rooms could be freed from effects of echo by lining the walls and ceiling in such a manner.

So it was clearly realised about a century agó that one of the best remedies for removing the acoustical defect of a room is to introduce a sufficient area of a sound absorbing material.

The problem of measuring sound absorption coefficients of different materials and utilising these data in the acoustical treatment of rooms is getting more important, since any design of recording or broadcasting studio presupposes a knowledge of the acoustical quality of the chamber, in other words a knowledge of the absorption coefficients of the materials to be used in the interior finish of the chamber.

THEORETICAL WORK ON SOUND ABSORPTION

The relation between the absorption coefficient of a material and its porosity was first deduced by Lord Rayleigh (1883). He dealt with the case of sound incident normally on a flat surface perforated by a great number of similar channels perpendicular to the face. The channels were supposed to be cylindrical and that expansion and rarefaction of air within these channels took place isothermally. The depth of the pores was assumed to be small compared to the wavelength of sound, but sufficiently large relative to the diameter of the pores and the portion of the sound energy entering the pores to be completely dissipated. His expression for the absorption coefficient (a) is

$$a = \frac{4M}{2M^2 + 2M + 1} \qquad \ldots \quad (1)$$

where, $$M = \frac{2(1+g)\sqrt{\nu\gamma}}{r\sqrt{w}}$$

and g = ratio of unperforated to perforated areas of porous surface.

ν = kinematic viscosity of the gas.

γ = ratio of the specific heats of the gas.

r = radius of the pores.

$w = 2\pi \times$ frequency.

In a later paper Rayleigh (1920) dealt with the case of sound waves incident at any angle on a porous wall and found that the amplitude of the reflected waves depends on the angle of incidence, the amplitude of the reflected beam (B) and the angle of incidence θ being given by the relation

$$\frac{B-1}{B+1} = \frac{\sigma}{\sigma+\sigma'} \cdot \frac{1}{\cos\theta} \cdot \frac{K'\tan K'l}{iK} \qquad \ldots \quad (2)$$

where, σ = area of the perforated surface.

σ' = area of the unperforated surface.

$$K' = K^2 - \frac{iwh}{v^2}$$

$K = 2\pi/\lambda$

$w = 2\pi f$

h = Rayleigh's dissipation factor.

v = Velocity of sound in air.

l = Depth of the pores.

Assuming the energy of the incident wave to be unity the absorption coefficient is given by

$$a = 1 - B^2$$

This formula does not give a direct relation between the absorption coefficient for any angle of incidence and the porosity of the sample and the frequency of the sound wave incident on the surface.

The theoretical aspect of the present investigation, therefore, led us to use the Rayleigh equations and deduce a more general formula. From eq. (2)

$$B = \frac{(1+g)\cos\theta - x}{(1+g)\cos\theta + x} \quad \text{where,} \quad x = -\frac{K'\tan K'l}{iK} \quad \text{and} \quad g = \frac{\sigma'}{\sigma}.$$

Therefore

$$a_\theta = 1 - B^2 = 1 - \left\{ \frac{(1+g)\cos\theta - x}{(1+g)\cos\theta + x} \right\}^2 = \frac{4(1+g)\cos\theta x}{\{(1+g)\cos\theta + x\}^2}.$$

Replacing the value of x by

$$x = \frac{(2M^2+1) \pm \sqrt{4M^4+1}}{2M/(1+g)}$$

the final equation becomes

$$a_\theta = \frac{8M\{(2M^2+1) \pm \sqrt{4M^4+1}\}\cos\theta}{\{(2M^2+2M\cos\theta+1) \pm \sqrt{4M^4+1}\}^2}. \qquad \ldots \quad (3)$$

This reduces to the expression for normal incidence as found by Rayleigh by putting $\theta = 0°$

$$a_0 = \frac{4M}{2M^2+2M+1}.$$

For calculating theoretically the absorption coefficient of a given material it will be, therefore, necessary to ascertain the value of M and correlate the value with different inclination for different values of absorption.

PREVIOUS METHODS OF MEASUREMENT

Reverberation Method.—Sabine (1895) first started experimental investigation on absorption coefficients of different materials. His method consisted of finding, by means of a stop-watch, the reverberation periods first of a chamber without and then with the test sample and calculating the absorption coefficient from the difference of the two periods of reverberation. The ear was used as a detecting instrument and the threshold of hearing was fixed as the point of reference. His method has been subsequently modified by Wente and Bedell (1930) and Olson and Kreuser (1930) and further by the U. S. Bureau of Standards (1930) in which the electro-acoustic devices have been used for producing and detecting the sound.

The reverberation method gives a more practical value of absorption coefficient as here the test sample is subjected to sound waves incident upon it in random manners from all directions, just as in practical field of application. But small samples cannot be tested by this method as in this case it is necessary that the area covered by the test sample should be comparable to the area of the room, so that there may be a measurable difference between the two time periods. Moreover large test rooms are required so that there may be a uniform mixing of sound energy throughout the room.

Stationary Wave Method.—The stationary wave method of measuring the absorption coefficient of small samples was suggested by Tuma (1902) and subsequently modified by Weisbach (1910), later on by Taylor (1913) and Paris (1927). In this method a long metal tube, with walls thick enough to prevent them vibrating appreciably, is provided with a source of sound at one end and closed at the other end by the test specimen. Sound waves from the generator travel down the pipe and is incident normally upon the sample where a portion of it (depending on the absorption coefficient of the sample) is reflected back to the other end of the tube giving rise to a stationary wave system. Pressure amplitude varies continuously along the pipe passing through a series of maxima and minima, and the absorption coefficient of the test sample is given by

$$a = \frac{4}{2 + \frac{A}{N} + \frac{N}{A}}$$

where, N and A are equal to maximum and minimum amplitudes respectively.

This method yields values of absorption coefficients of small samples at normal incidence only. Heyl, Chrisler and Snyder (1930), working at the U. S. Bureau of Standards, modified the stationary wave apparatus for investigation on the absorption coefficient of sound at oblique incidences but their method yielded abnormal results contrary to those obtained from theoretical considerations. Paris (1930) discussed about the drawbacks of their apparatus and the unsuitability of determining the absorption coefficients at oblique incidences by the stationary wave method.

Watson's Method.—Watson (1922) devised a method by which the absorption coefficient is calculated from a direct measurement of sound waves transmitted and reflected by the test sample. Sound emanating from the source, an organ pipe placed at the focus of a paraboloidal reflector, undergoes reflexion and transmission from the test sample clamped over an aperture between two adjacent rooms and then passes to the measuring instrument, a Rayleigh Disc with suitable resonators. This method has been adopted by the National Physical Laboratory (1927) with the modification that electrical equipments have been used in the method of producing and measuring sound.

This method has the advantage that by varying the angle of incidence of the sound waves upon the test sample, the absorption coefficients for different angles of incidence can be studied and samples of any size can be tested simply by making the beam of sound large enough to cover the whole surface.

Kuhl and Meyer (1932) adopted this method to measure the relation of absorption to angle of incidence but they carried out the experiment in the open air on the flat roof of their Institute.

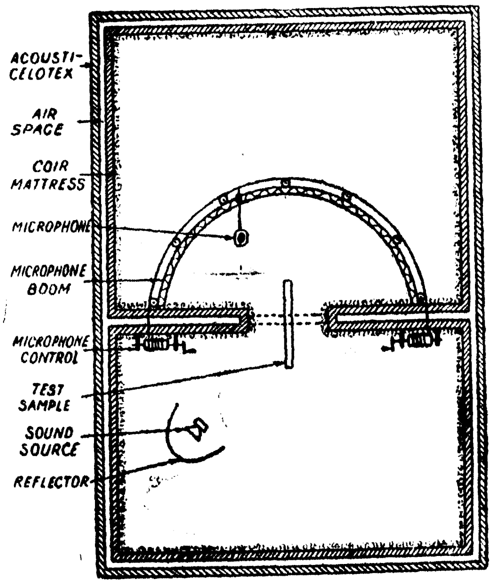
PRESENT METHOD OF MEASUREMENT

The present method of measurement is a modification of the Watson's method and consists in measuring the absorption coefficient of the test sample at various angles of incidence over the audio frequency band. It involves the measurement of the amplitude of the sound wave reflected first from a complete reflector and then from the test sample and the diminution of the sound energy in the second case is due to absorption of sound energy by the sample. If B_1 and B_2 be the amplitudes of the beam reflected from the complete reflector and the test sample respectively and since sound energy is proportional to the square of the amplitude, the absorption coefficient a is then given by

$$a = \frac{B_1^2 - B_2^2}{B_1^2}.$$

The complete reflector used is a ¼″ thick metal plate backed by a 2″ thick wooden board. The investigation has been conducted in an especially constructed sound chamber and the relative amplitudes in the two cases have been measured by means of electrical devices.

Sound Chamber.—The sound chamber is planned and constructed in such a way as to attain a low time of reverberation and high insulation from external noises. It is a rectangular room 20 feet by 15 feet by 10 feet proportional to the dimensions recommended by the American Standards and situated inside another big room having thick brick walls and concrete floor and ceiling. The chamber is divided into two portions by means of a thick partition wall, the source of sound is placed in one of them while measurements are carried out in another. There is a window 2′ × 2′ in the partition wall for holding the test sample. All exposed surfaces inside the rooms are heavily lagged with sound absorbing materials to suppress reflexions from the surfaces and minimise interference phenomena. The walls have been treated with a layer of acoustic celotex followed by 4 inches of air gap and then 4 inches thick mattresses of cocoanut fibres. The ceiling is treated with acoustic celotex and 6 inches cotton wool padding. The floor is covered with a thick lining of fibrous mattresses. The inside acoustical treatment of the room has also helped to reduce the intensity of sound in the region outside the main beam. Fig. 1 shows the plan view of the room. The reverberation time of the room was found to be very low.



PLAN VIEW OF THE SOUND CHAMBER

FIG. 1

Source of Sound.—The source of sound is a dynamic type loudspeaker fed from a high grade beat-frequency oscillator, the output of which can be varied by means of a calibrated attenuator. The quality of the tone produced by the source has been checked by receiving the sound through a velocity microphone in conjunction with a high grade resistance-coupled amplifier and examining the wave form of the output on a cathode ray oscillograph.

The source of sound is placed at the focus of a paraboloidal reflector to obtain a parallel beam of sound directed towards any particular direction. Measurements of the intensity of sound on the central axis of the beam at a distance of 3 feet from the source and also at points off-axis show that the incident beam is moderately uniform over a width of about 2 feet and drops down beyond that to a marked degree. The result for one frequency is shown in Fig. 2.

While carrying on preliminary investigation, the result was found to vary depending on the distance between the test sample and the source of sound and it was due to the formation of stationary wave-pattern inside the chamber. In order to minimise this effect the pattern has been made to shift continuously from one position to another by varying the frequency of the source through a narrow band, that is by warbling the tone. This is accomplished by means of a small variable air-condenser rotated by a constant speed motor and placed externally in parallel with the main tuning condenser of the beat-frequency oscillator. The band width of warbling was kept under experimental control as the variation of capacity of the rotating condenser could be adjusted by means of a cam arrangement. The segment of rotation was such that the frequency shifts were about 8 times per second. The band width has been chosen so that they were approximately 10% of the middle frequency band. The formation of stationary wave pattern and the effect of the warbled tone on its suppression are shown in the Fig. 3.

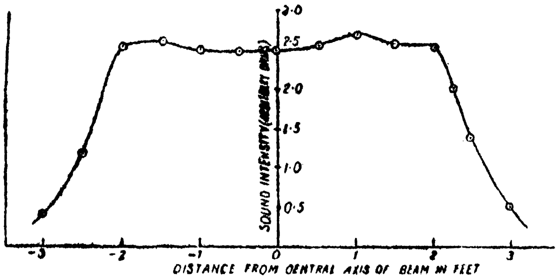


FIG. 2

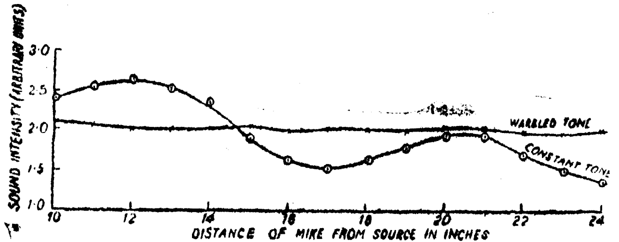


FIG. 3

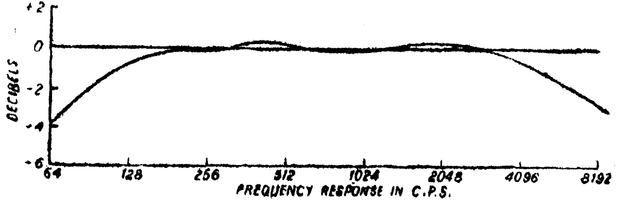


FIG. 4

A milliammeter was connected in series with the input to the loud speaker so that the energy input to it at a given frequency could be kept constant during a set of observations.

MEASUREMENT OF AMPLITUDE OF SOUND WAVE

The amplitude of the sound wave is measured by means of a velocity microphone connected to a high-gain amplifier, the output of which was indicated by a valve-voltmeter. The overall characteristic of the microphone and the amplifier combined is shown in Fig. 4. The position of the microphone inside the chamber was controlled from outside by swinging it on a boom by means of a remote control arrangement as shown in Fig 1. Fig. 5 shows a schematic diagram of the complete equipment.

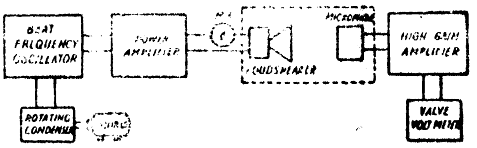


FIG. 5

EXPERIMENTAL RESULTS

The materials tested are: (1) Indian white cotton, (2) Silk cotton, (3) Cocoanut fibres and (4) Jute fibres. Test samples have been first of all prepared from these materials.

White cotton and Silk cotton have been loosely packed inside thin cotton fabric bags and made into a thickness of 2 inches.

Cocoanut fibres are woven into 2 inches thick mattress with the fibres arranged in such a manner so that they lie side by side and their tips form t surface of the sample.

Jute fibres are cut into pieces 2 inches long and they are fixed side by side by means of wire nettings, the tips of the fibres forming the surface of the sample.

The values of the absorption coefficients of the four samples at different audio frequencies and for various angles of incidence are given in Table I to IV.

TABLE I

Indian White Cotton

Angle of Incidence	Sound Absorption Coefficients for frequencies in cycles per sec.							
	64	128	256	512	1024	2048	4096	8192
15°	.10	.17	·33	·46	·57	·48	·45	42
30°	.14	.20	·34	·48	·58	49	.46	44
45°	.19	.225	·40	·50	.62	·51	·49	·465
60°	.225	.30	·43	·58	.68	.60	·51	·50
75°	.23	.31	.425	·58	.66	·59	·495	·49

TABLE II

Silk Cotton

Angle of Incidence	Sound Absorption Coefficients for frequencies in cycles per sec.							
	64	128	256	512	1024	2048	4096	8192
15°	·22	·25	·35	·51	.60	·57	·48	·415
30°	·24	·265	·365	52	.625	.60	·50	·42
45°	·25	·30	·40	·55	.64	.62	·53	·435
60°	·30	·34	·44	.60	·70	.63	·55	·52
75°	·33	·40	·43	.61	.68	59	·54	·50

TABLE III

Cocoanut Fibres

Angle of Incidence	Sound Absorption Coefficients for frequencies in cycles per sec.							
	64	128	256	512	1024	2048	4096	8192
15°	·225	·25	·34	·52	.68	·72	·54	·48
30°	·24	.26	·345	·535	.69	·775	·56	·50
45°	·25	·29	·37	·575	·71	·78	.60	·53
60°	.28	·32	·395	.64	·75	.80	.635	·575
75°	·32	·33	·43	.67	·76	·79	.65	·57

TABLE IV

Jute Fibres

Angle of Incidence	Sound Absorption Coefficients for frequencies in cycles per sec.							
	64	128	256	512	1024	2048	4096	8192
15°	·295	·47	70	81	·72	.64	·55	.48
30°	·31	.485	·72	.83	·735	.655	58	·52
45°	·34	·52	·75	.865	·78	.685	.61	·575
60°	·38.	·54	80	.89	.81	·72	.67	.62
75°	·40	.62	.83	·91	.81	·73	.69	.63

CONCLUSION

From tables I to IV it is found that absorption coefficients of all the samples tested vary with the angle of incidence as well as with the frequency.

The value of the absorption coefficients gradually increases with the angle of incidence and attains maximum value at about 60° in some cases and in some cases it goes on increasing up till 75° up to which measuremonts have been taken.

It is in agreement with the results deduced from the equation based upon the theory of Rayleigh. It also confirms the results derived by Paris from the conception of " Acoustical Admittance."

As regards variation of absorption coefficient with frequency it is seen that White cotton and Silk cotton attain maximum values at 1000 c.p.s., Cocoanut fibres at 2000 c.p.s. and Jute fibres at 500 c.p.s.

The value of the absorption-coefficients as calculated theoretically from the dimensions of the pores and porosity of the sample and relation between the theoretical and measured values will be dealt in the subsequent paper (Part II.)

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