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ABSORPTION OF SOUND BY POROUS MATERIAL I

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Zusammenfassung

Von einer Holzfaserplatte und von einer Platte aus akustischem Putz sind die Porosität und Luftwiderstand gemessen. Mit Hilfe dieser Messwerte sind unter Benutzung älterer Theorien die zu erwartende akustische Schluckzahlen berechnet.

Andererseits sind diese Schluckzahlen direkt gemessen; für senkrechten Einfall unter Benutzung einer Interferenzmethode und für allseitigen Einfall mittels einer Nachhallmethode mit konstanter Tonhöhe.

Die Abb. 5, 7 und 8 zeigen in wie weit Übereinstimmung besteht zwischen Theorie und Experiment. Offenbar trifft die Theorie in ungenügender Weise zu.

§ 1. More than once already one has derived mathematically a formula for the absorption coëfficient of porous walls, expressing its dependence upon the porosity, the angle of incidence, the specific resistance of the air and the thickness of the material [1]). Most complete of all in this respect is Monna's work, in which, moreover, the other publications are criticized. The formula, derived by Monna, is rather complicated. The quantities introduced by him to describe the absorption are, apart from the thickness and the angle of incidence, which are defined in the usual way, the cavity-factor h, being the percentage of the volume occupied by air, and the specific resistance σ of the porous material for a steady flow of air (therefore, $-\text{grad}\, p = \sigma \mathbf{v}$).

In order to make a comparison possible between the theoretical results obtained and the values for the absorptioncoëfficient following from measurements on the reverberation, it was necessary to compute from the values of the absorptioncoëfficient a_α belonging to the variable angle of incidence α, the average value $\bar{a}$ by means of the formula

$$\bar{a} = \frac{\int_0^{\pi/2} a_\alpha \, 2\pi \sin\alpha \cos\alpha \, d\alpha}{\int_0^{\pi/2} 2\pi \sin\alpha \cos\alpha \, d\alpha} = 2\int_0^{\pi/2} a_\alpha \sin\alpha \cos\alpha \, d\alpha.$$

Owing to the fact that a_α is a complicated function of cos α, it was not possible to calculate $\bar{a}$ accurately by an integration. Taking into account, however, that the weight-factor sin α cos α has a maximum value for $\alpha = 45°$, one can assume as a first approximation $\bar{a} = a_{45}$.

We have tried to test M o n n a's results experimentally. To that end, we have determined directly the cavity-factor h and the specific resistance for air σ of a few materials and substituted the values, found in this way, in M o n n a's formulae for a_0 and a_{45}, we have then examined whether the values, computed in this manner agree with the values of the absorptioncoëfficient, determined acoustically for normal incidence and for incidence from all directions respectively.

§ 2. Availing ourselves of B o y l e's law: $p_1V_1 = p_2V_2$, we determined the cavity-factor h by means of the apparatus shown in fig. 1. The specimen of known external volume was placed in the vessel of volume V_0. In order to get rid of any water kept back by capillary forces, this vessel was a few times evacuated and refilled with dry air. The increase of volume was effected by opening tap F and by introducing a few of the spheres of volume V' etc., which was done by lowering vessel B. The change of the pressure was measured with the paraffin manometer E. Meanwhile the level at C was kept at the same heigth, with a view to eliminate any changes of volume in the manometer. For that reason tube D was applied.

The accuracy of the measurements was amply sufficient; we were able to measure h as far as two decimal places.

In the above way only those pores, communicating with the air outside are measured, but those are precisely the ones, with which we are concerned.

§ 3. We measured the specific resistance of the air with the aid of an arrangement, given in outline in fig. 2. On the specimen A is placed a box B in which, by partially pumping away the air, an under-atmospheric pressure is created. This pressure is measured with a F u e s s-micromanometer (*D* in fig. 2). The velocity of the current is measured by a current-meter *C*, which is calibrated beforehand.

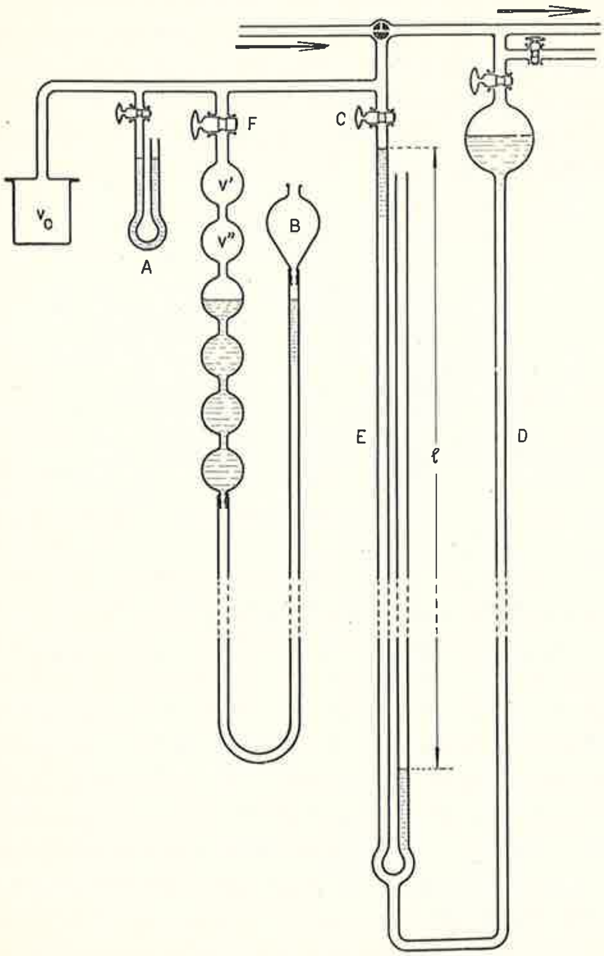

Fig. 1. Apparatus for measuring the cavity factor.

In order to prevent any radial currents in the specimen box *B* is surrounded by a wider box *F*, in which the pressure is kept at exactly the same value as in *B*. This equality was checked by means of the drop of alcohol *H*, which was to remain at rest inside the capillary *J* and the immobility of which was observed with a microscope. Box *P* was fastened along the edge on the specimen A by means of plaster of Paris.

The under-pressure applied was of the order of 2 to 0,02 mm H_2O; the pressures in B and F could be adjusted to the same value with sufficient accuracy, as appeared from the smallness of the spreading in the measuring points. The measured values for the air-resistance per cm^3 were of the order of 10000 dynes sec/cm^4 for a certain kind of woodfibre plates and for plates of acoustic plaster they were of the order of 100 dynes sec/cm^4.

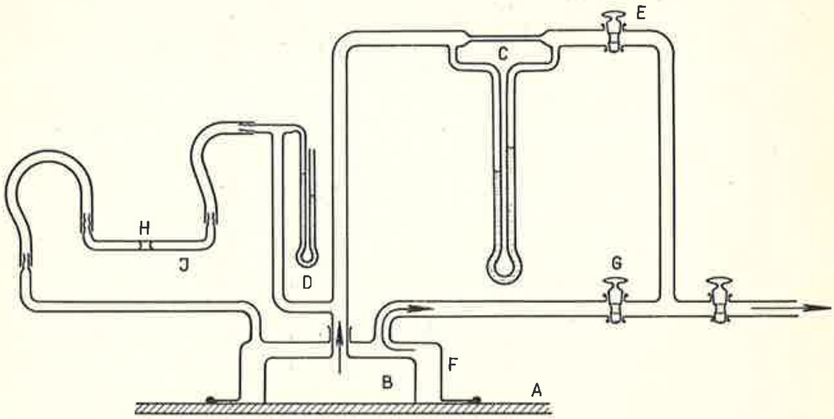

Fig. 2. Apparatus for measuring the permeability.

The air-resistance turned out to be indeed independent of the value used for the under-pressure. Some caution was necessary in connection with the watercontent of the specimen. Immediately after the plaster of Paris was applied, the results obtained for woodfibre plates appeared to be irregular; this must in all probability be ascribed to the swelling of the material under the influence of its increased watercontent.

§ 4. The measurements of the absorptioncoëfficient for normal incidence were carried out according to the method of stationary waves [2]), the sound pressure in the wave-system being measured in the places of the maxima and minima. The area of the specimina used was 400 cm^2. The details of our arrangement will be published elsewhere.

For the measurements of the average absorptioncoëfficient specimina were used of 5,5 m^2, placed in a reverberation-chamber of 164,5 m^3. We performed series of experiments at constant frequencies and during the emission of sound the loudspeakers were revolving, while the microphone was moved in the reverberation-chamber In order to average over the places of nodes and anti-nodes the reverberation time was determined at each frequency for 100 different positions of loudspeaker and microphone. The arrangement started and stopped working automatically, a counting mechanism gave us the number of reverberation-periods and the added-up time of reverberation was read from an electrical clockwork. The measuring arrangement is shown in its general outline in fig. 3.

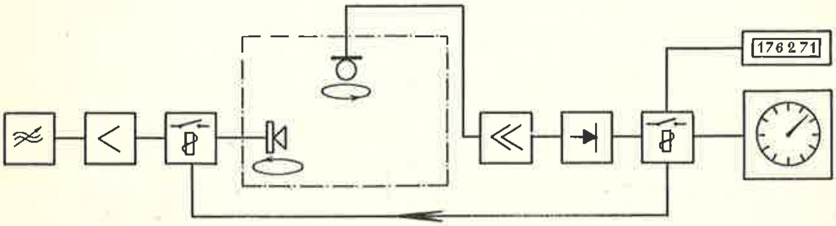

Fig. 3. Set up for the measuring of the reverberation time.

The output of a soundgenerator reaches after due amplification via a relay the revolving loudspeakers, mounted in the reverberationchamber. After the loudspeakercircuit is opened, the intensity of the sound in the chamber begins to decrease, thereby causing a decrease in the amplified and rectified voltage of the microphone. At a certain pre-determined value of the voltage the clockwork is set going, and at a lower voltage, also pre-determined, it stops, while at the same time the catch of the counting-mechanism moves and the loudspeakers are switched in again.

Fig. 4 shows the relay-arrangement in more detail. 1 and 2 are thyratrons. The three discs in the figure are in reality only one disc, set into a sliding motion by a small motor (not shown).

With the lowering of the sound level in the reverberation chamber the rectified tension is also lowered, whereby thyratron 1 comes into action. The plate-current operates relay *A*, the clockwork is set going and the grid-circuit of 1 is opened, so that no grid-current can occur. A few moments later 2 comes into action, by which relay *B* is operated, the grid-circuit of 2 is opened, the clockwork stops, the counting mechanism gives a jerk and the catch is pulled out of the notch in the disc, so that the latter no longer slides but starts revolving in the indicated direction. From this it follows that the plate circuits of the thyratrons are opened and that the relays *A* and *B* resume their rest positions. The catch then falls back on the disc, so that this is stopped after one revolution. Relay *C* is then operated, by which the loudspeaker circuit is closed. After one revolution of the disc the rectified tension is once more a maximum; shortly after the disc has been caught, the loudspeaker circuit, therefore, has been opened and tension once again exists on the plates of the thyratrons, thyratron 1 comes into action etc.

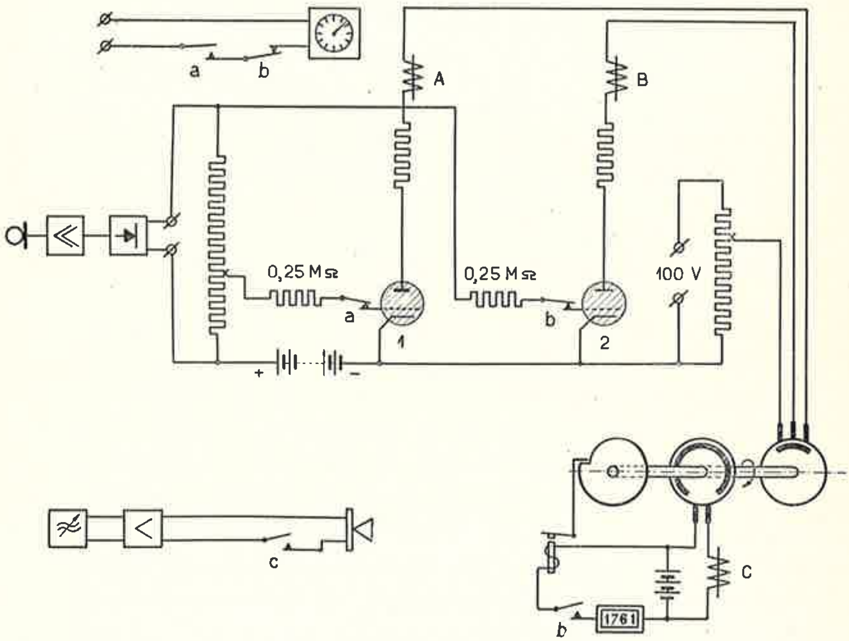

Fig. 4. Relay arrangement as used in measuring the reverberation time.

§ 5. *Measurements on woodfibreplates.* Measurements were performed on woodifbre plates of a thickness of 12 mm. For the average result of a great many measurements on this material we found:

$$\text{cavityfactor } h = 0{,}80$$

air-resistance, per cm^3, $\sigma = 6000$ dyne sec/cm^4.

On substituting these values in M o n n a's formulae our computation of the absorptioncoëfficient yields for 500 Hz,

in the case of normal incidence . . . . $a_0 = 5\%$

in the case of 45° incidence . . . . $a_{45} = 7\%$.

These values are considerably lower than those generally found from direct measurements of the absorption. As is well-known it is not the same whether the plates can vibrate freely over their full extent or not, but also for plates stuck with their entire area on a hard backwall, values for the absorptioncoëfficients have been measured, lying between 15% and 20%.

Our own measurements yield results for this material of which the comparison with M o n n a's theoretical values is shown in fig. 5.

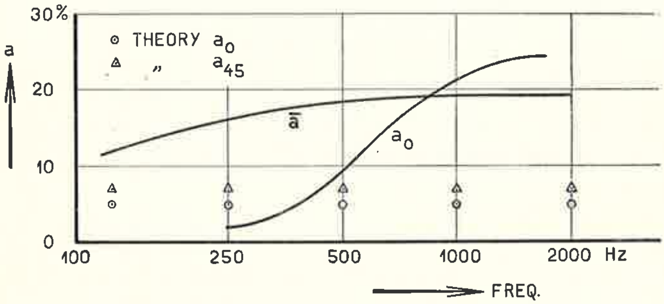

Fig. 5. Comparison of the measured absorption coefficients (full line) of a wood fibre plate with the theoretical prediction of M o n n a.

We have examined whether any possible inhomogeneities of the material might be the cause of the discrepancy between the measured and the computed absorptioncoëfficients. These inhomogeneities are of a twofold nature. In the first place the pores are not, all of them, of the same size and in the second place it may be that the outer layers of the plates are more tightly compressed than their inner parts, owing to the way in which the plates are made.

If the spreading in the diameter of the pores be such, that a few large openings occur, its influence on the result will be especially noticeable, for then the measured value for the resistance of the air will come out too small. This means that we should have to substitute in M o n n a's formulae a higher value for σ than the measured one. This, however, would lead to a still smaller value for the computed a (cf. fig. 6), so that the discrepancy would only become still more pronounced.

The assumption of a hard surface-layer leads also in the wrong direction. For the outer layer will have a greater influence on the absorption of sound than the inner parts. In our determination σ is averaged over the entire thickness of the plate and this value is lower than the one for a more rigid top layer, if that should be present. Any possible correction would, therefore, consist in introducing an increased value for σ in M o n n a's formulae and this, as is clear from fig. 6, leads in the wrong direction.

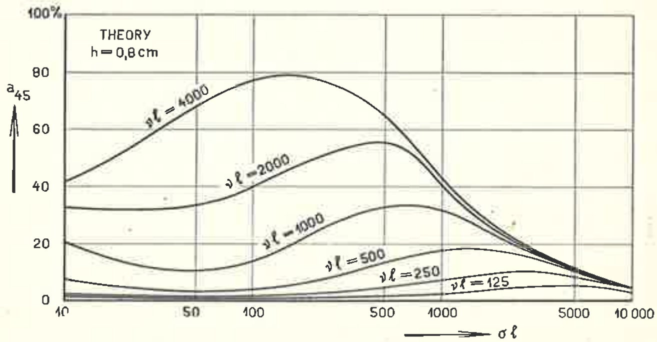

Fig. 6. The absorption coefficient for a 45 degree angle of incidence as a function of the specific air-resistance σ, frequency ν and plate thickness l for a cavity factor 0,80 according to M o n n a.

From the foregoing we draw, therefore, the conclusion that the damping due to porosity, as computed by M o n n a and others, is in the case of woodfibre plates not the most important one, but that there must exist, besides, other effects, to which at least an equal amount of damping must be ascribed.

§ 6. *Measurements on porous plaster.* We made some porous plates of the kind, commercially known as ,,Sorbolite'', thickness 3 cm. The average value of the cavity-factor h turned out to be 0,63, while the average result of a number of determinations of the specific air-resistance was 51 dyne sec/cm^4. The value of a_0, computed with these values according to M o n n a's formula is compared below (see fig. 7) with the value measured by us according to the interference method.

The average a was measured on specimina of a thickness of 1,5 cm and for a great many frequencies according to the reverberation method. The little circles in fig. 8 indicate the theoretical expectation according to Monna's formulae with $h = 0{,}63$ and $\sigma = 51$ cgs for $\alpha = 45°$. The agreement between the computed and measured

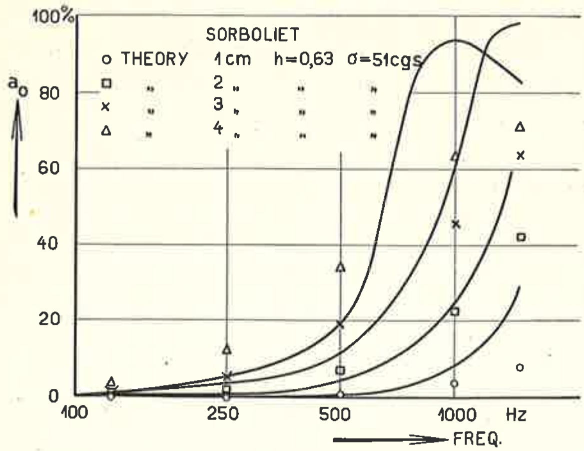

Fig. 7. Comparison of the measured absorption coefficients (full drawn curves) of an acoustical plaster with the theoretical prediction of Monna's. Normal incidence.

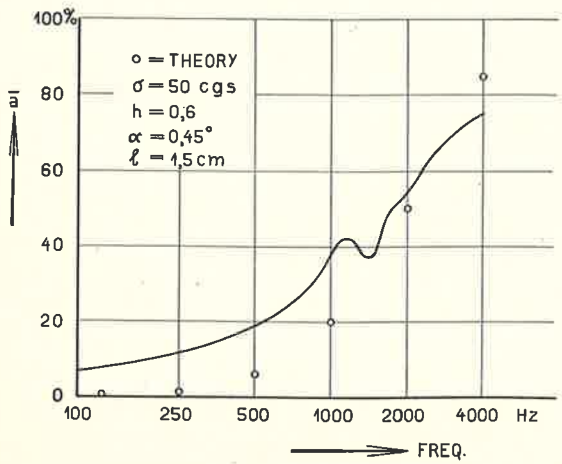

Fig. 8. Comparison of theory and experiment for an acoustical plaster. The absorption coefficient resulting from reverberation-measurements is compared with the theoretical a-value for a 45 degree angle of incidence.

values is satisfactory for the higher frequencies. For lower frequencies this is no longer true and this time again the computed values are considerably lower. As is well-known, measuring of the absorptioncoëfficient according to the reverberation-method is liable to show a wide spreading in the results especially at lower frequencies, but even after having duly reckoned with this fact, there remains, none the less, a pronounced difference between the results.

In a second article we hope to enter into the cause of the discrepancy between theory and measurements.

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2) For various instrumental embodiments see Davis: Modern Acoustics, p. 211, London, 1934; For theory see Wente and Bedell: The Bell System Technical Journal **7**, 1—10, 1928.