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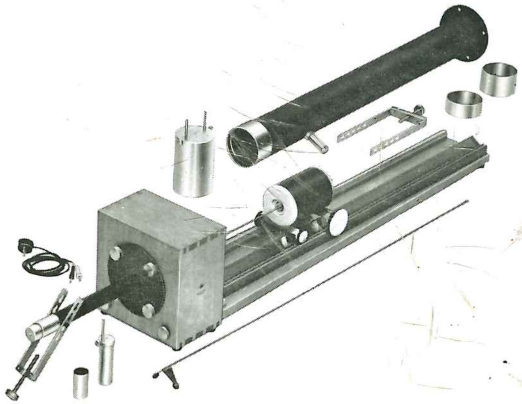
4002

INSTRUCTIONS AND APPLICATIONS

Standing Wave Apparatus Type 4002



For measurements of specific airborne acoustic absorption and impedance of material samples. Covering a frequency range from 95 to 6500 Hz.

Accelerometers
Acoustic Standing Wave Apparatus
Artificial Ears
Artificial Voices
Audio Frequency Response Tracers
Audio Frequency Spectrometers
Audio Frequency Vacuum-Tube Voltmeters
Automatic A.F. Response and Spectrum Recorders
Automatic Vibration-Exciter Control Generators
Band-Pass Filter Sets
Beat Frequency Oscillators
Complex Modulus Apparatus
Condenser Microphones
Deviation Bridges
Distortion Measuring Bridges
Frequency Analyzers
Frequency Measuring Bridges
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Variable Frequency Rejection Filters
VHF-Converters
Vibration Pick-ups
Vibration Pick-up Preamplifiers
Wide Range Vacuum Tube Voltmeters

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BB 4002

Standing Wave Apparatus

Type 4002

Reprint March 1967

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Description

The apparatus Type 4002 is designed for easy and quick determination of the absorption coefficients of acoustical materials by the standing wave method. The advantages of the method are that only small circular samples, about 10 cm in diameter, are needed, and the measurements are easy to carry out and are perfectly reproduceable. However, as the largest dimension of the sample, according to the principle of the measuring method, which requires plane sound waves in the measuring tube, must not be larger than about half the wave length of the sound at the measuring frequency, it is impossible to obtain reliable results for materials, the absorption ability of which depends on their extent, as, for example, vibration panels, large slit resonators, etc. The tube method is therefore particularly suited to measurements of porous materials, ordinary resonance absorbents, light membrane absorbents, etc.

The principle of the measuring method is shown in Figs. 1 and 2. The loudspeaker at one end of the tube is operated at the desired test frequency from an audio-frequency oscillator with 6 ohms output impedance and with a distortion of less than 1 %. For this we recommend our B.F. Oscillator Type 1022. The sound waves move through the tube and strike the sample which is placed in a sample holder with a thick back plate, to avoid all sound absorption by the apparatus itself. The sound waves are then partly reflected at the sample. The resultant of the incident wave with amplitude 1 and reflected wave with amplitude r is a standing wave pattern with alternate sound maxima $1 + r$ and minima $1 - r$ in the tube. From the ratio n of these sound pressure maxima and minima the reflection coefficient r follows directly,

$$|r| = \frac{n - 1}{n + 1} \qquad (1)$$

However, we are more interested in the absorption coefficient α, i.e., the ratio of the energy absorbed by the sample to the incident energy. In other words $\alpha = 1 - |r|^2$, from which, with the aid of relation (1), follows directly,

$$\alpha = \frac{4}{n + \frac{1}{n} + 2} \qquad (2)$$

(see Fig. 3)

The sound field is explored by means of a probe microphone, moveable on a track equipped with a scale on which the exact distance between probe entrance and test sample can be read. The microphone voltage should be amplified by a selective amplifier to reduce the influence of hum and noise

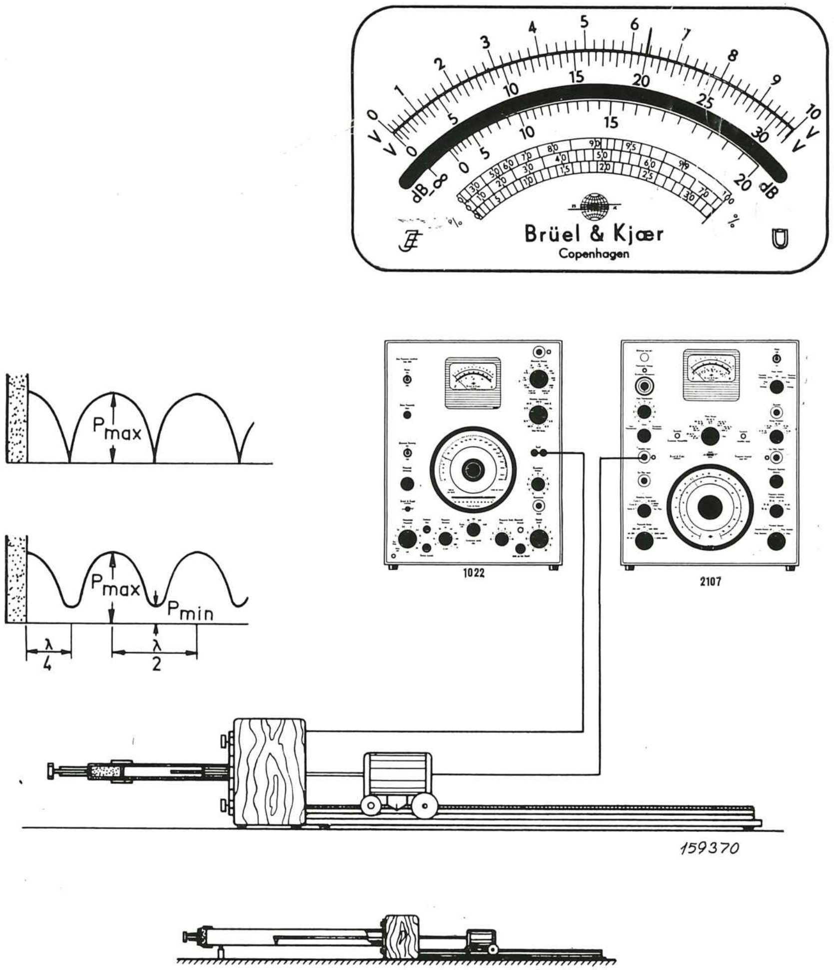

Fig. 1. Measurement of acoustic absorption coefficient with the aid of Frequency Analyzer 2107. (Constant Percentage Bandwidth Type).

and higher harmonics, which are inevitably generated by the loudspeaker in the tube.

Particularly suitable for this purpose is the Frequency Analyzer 2107 (of the constant percentage bandwidth type), which is continuously tunable in the frequency range from 20 Hz to 20ooo Hz, or the 1/3 Octave Analyzer 2112 (Fig. 2), with 33 fixed filters from 22 Hz to 45 kHz. Both Type 2107 and

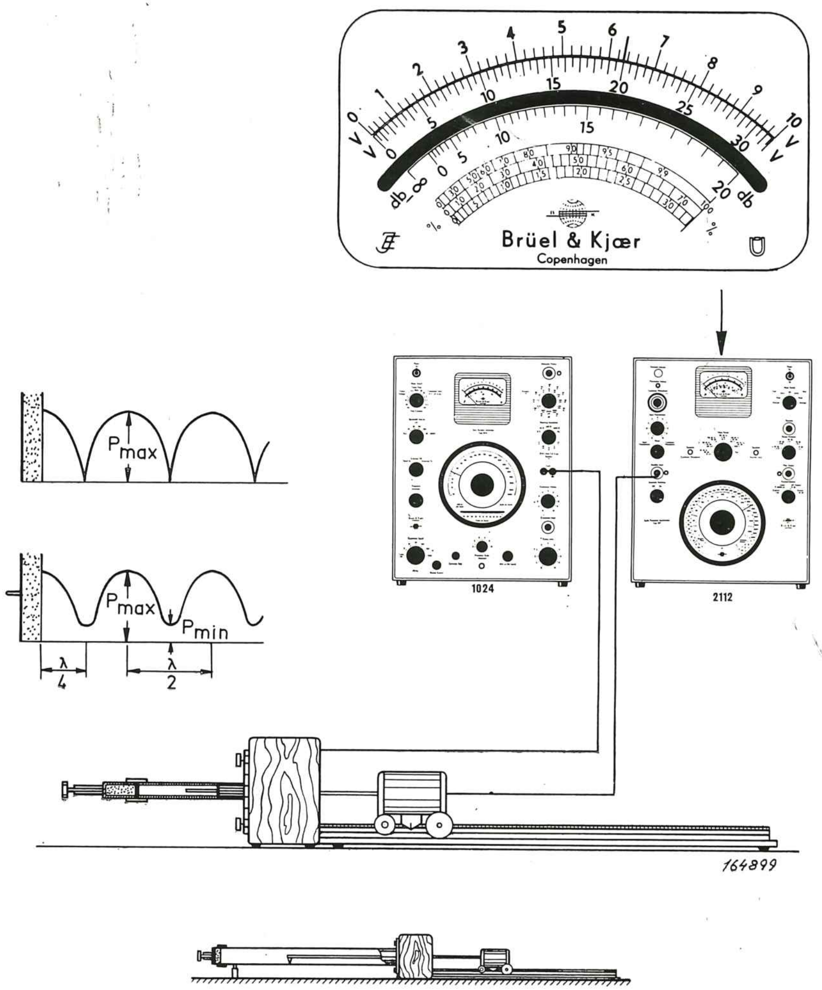

Fig. 2. The Standing Wave Apparatus Type 4002 mounted for low frequency 1/3 Octave Analyzer 2112.

Type 2112 have three scales, 0—100 %, 0—70 %, and 0—30 % (by increasing the amplification 10 dB and 20 dB).

The absorption coefficient is determined by the tube measurement method only at normal incidence, which is why the measured coefficients are generally somewhat smaller than those determined by the reverberation room method according to W. C. Sabine's formula. In Fig. 4 a curve is shown

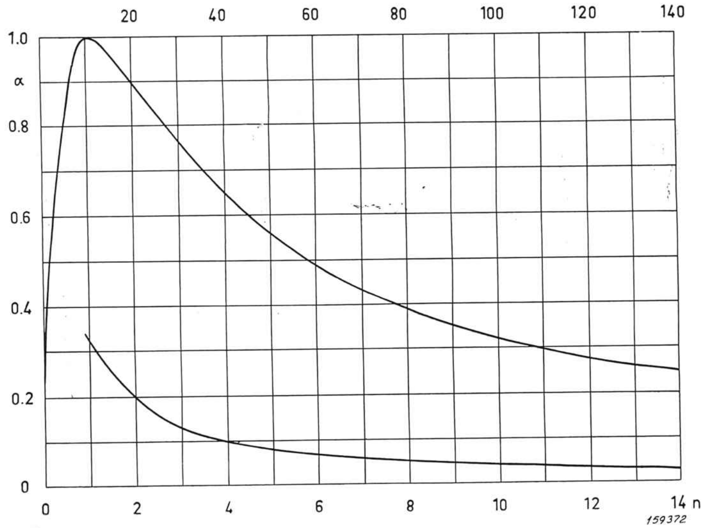

Fig. 3. Absorption coefficient α *as function of* $n = \frac{p\ max}{p\ min}$

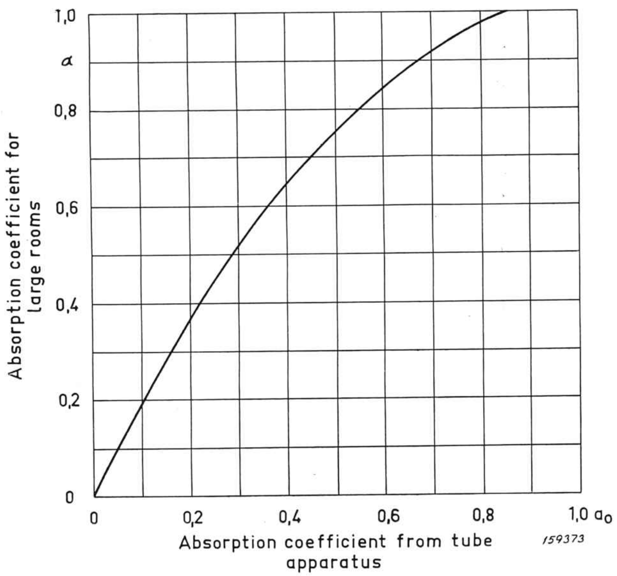

Fig. 4. Relation between absorption coefficient of large rooms and tube apparatus.

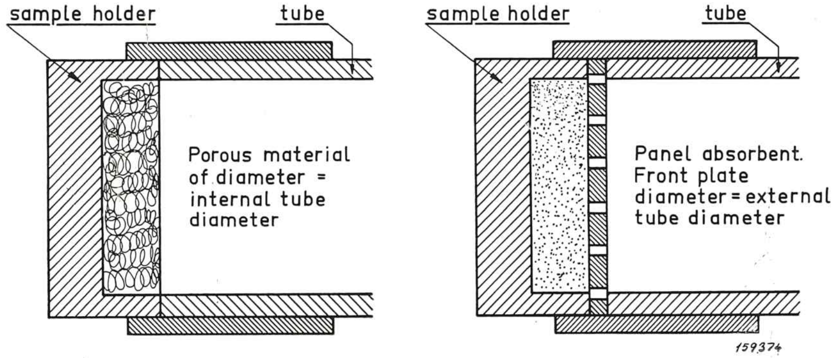

Fig. 5. Mounting absorbents in tube apparatus.

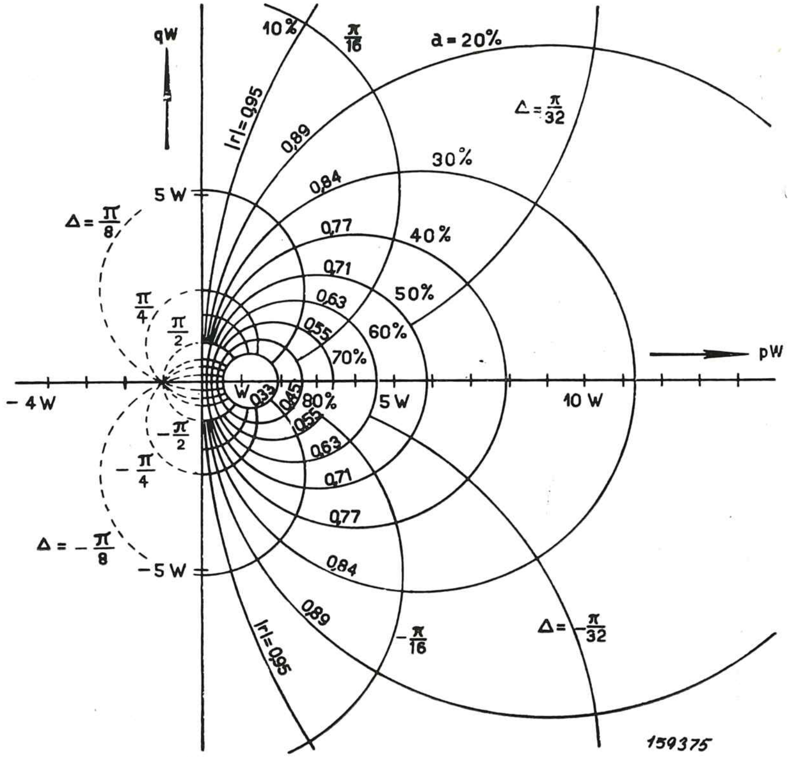

Fig. 6. Chart for obtaining resistive and reactive components of impedance Z with the aid of the measured α and Δ values.

which indicates the relation between the results of the tube method and the reverberation room method. This curve, though based on a theoretical foundation, must be taken with every possible reservation, as it is necessary that the reverberation room be very large, and the materials in the tube and reverberation room be placed in identical positions. This last requirement is very difficult to meet to any sufficient degree of accuracy, so that deviations often occur.

Below, some literature is given dealing with the measurement of acoustical impedance, and with a more detailed discussion of the tube method:

Bibliography:

Per V. Brüel: Sound Insulation and Room Acoustics. Chapman & Hall, London 1951. (1)

C. Zwikker, C. W. Kosten: Sound Absorbing Materials. Elsvier, New York, London, 1949. (2)

Leo L. Beranek: Acoustic Measurements. Wiley & Sons, New York 1949. (3)

Brüel & Kjær Technical Review, No. 1—1955.

Operation

The complete tube measurement apparatus comprises two measuring tubes; a large one with an interior diameter of about 10 cm, which covers the frequency range from 90 to 1800 Hz, and a smaller one with a diameter of about 3 cm, covering the frequency range from 800 to 6500 Hz. A set of holders for the samples is supplied for each tube. Two are fixed holders with depths of 1" and 2" respectively, and a third one has a variable depth. All the holders have a very thick base. The tube is screwed to the loudspeaker cabinet. The microphone probes are led through a hole in the loudspeaker, and are connected at the back of the cabinet with the microphone carriage, which runs on a track provided with a scale. The microphone lies in elastic mountings in the microphone carriage, well insulated from airborne noise and impact sound or vibrations.

A carefully cut circular sample of the material is placed in a suitable holder. (The sample is best cut with a bandsaw). Porous material is cut so that it fits the inside diameter of the holder, while absorption material with a hard covering plate, for example common resonance absorbents and membrane absorbents, is cut so that the hard plate fits the outside diameter of the holder, the soft back plate fitting the inside diameter (see Fig. 5). By mounting the material in this manner a very tight and effective fixing of the front plate is obtained. It is important that the bracing piece is screwed on tightly to prevent vibrations arising in the bottom of the holder.

The oscillator is connected to the loudspeaker terminals (6 ohms output impedance), and the jack of the probe microphone is connected to the input of the Frequency Analyzer 2107 or 2112 with INPUT SELECTOR on "Input Potentiometer". The oscillator is adjusted to the desired frequency and a suitable power output selected. The analyzer is tuned to the same frequency, but the selectivity is not chosen greater than is necessary. The analyzer deflection is regulated by its RANGE SWITCH, calibrated in steps of 20 dB. The fine adjustment is made by the INPUT POTENTIOMETER. The measurement itself is carried out as follows.

The microphone is placed at a sound pressure maximum and the deflection of the instrument pointer adjusted to 100 % by means of the INPUT POTENTIOMETER. The microphone is then moved to a minimum and the absorption coefficient read directly in % on the 100 %-scale of the instrument. With absorption coefficients less than 30 % the amplifier's gain can be increased by 20 dB by means of the METER RANGE switch on types 2107 and 2112. The absorption is then read off from the 0—30 %-scale. The extra 0—70 %-scale is used by increasing the gain only 10 dB by means of the RANGE MULTIPLIER switch.

At frequencies below 200 Hz the wave length is so great that it is impossible to find an isolated pressure maximum. It is then necessary to use the pressure immediately in front of the sample, which has practically the same value when the wave length is great. At higher frequencies it does not matter so much which maxima and minima are used, as the damping of the measuring tubes is very small. However, the highest accuracy is obtained by taking the maximum and minimum closest to the sample, but with perforated panels with big holes it is advisable to take the second maximum due to the inhomogeneity of the sound field close to the front of the sample.

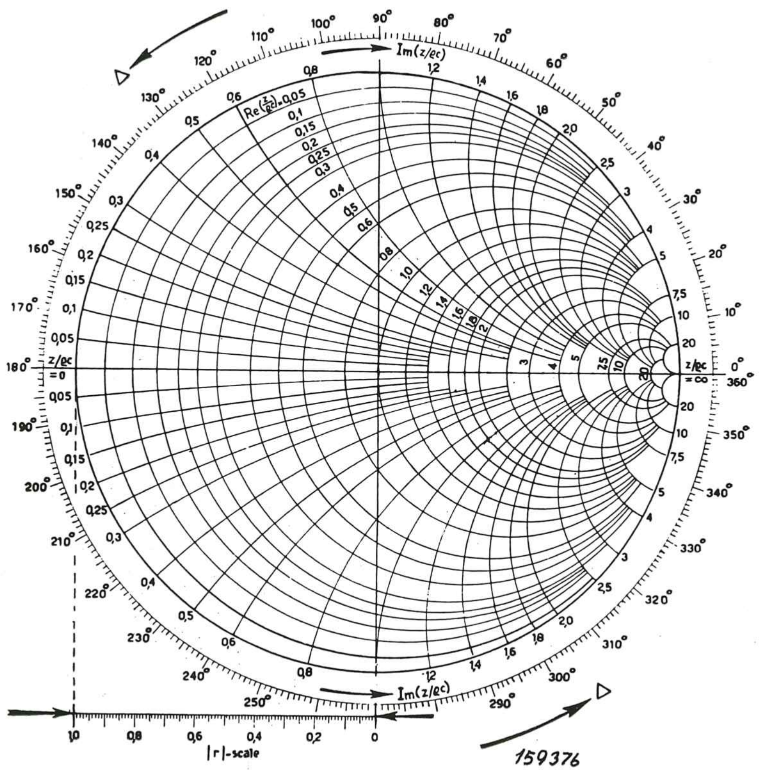

Fig. 7. Chart equivalent to Fig. 6. All values for $|r|$ and Δ, which fill the whole right half plane in chart 6 are here represented in a circle with radius 1.

In comparing the absorption coefficient of the same sample measured in the overlapping range 800—2000 Hz of the two tubes, the greater weight ought normally to be given to the results from the big tube, since small inhomogeneities in the sample have a bigger influence with the smaller diameter tube.

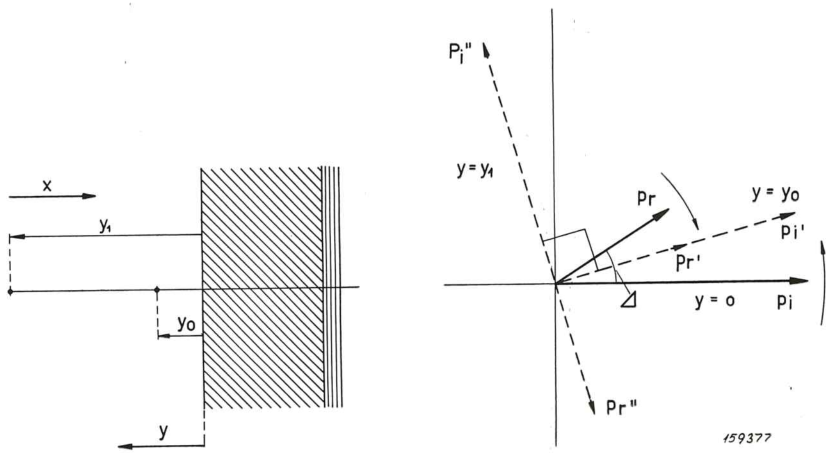

Fig. 8. Vector diagram indicating incident and reflected wave pressures p_i and p_r at sample surface ($y = 0$), first maximum ($y = y_0$) and first minimum ($y = y_1$).

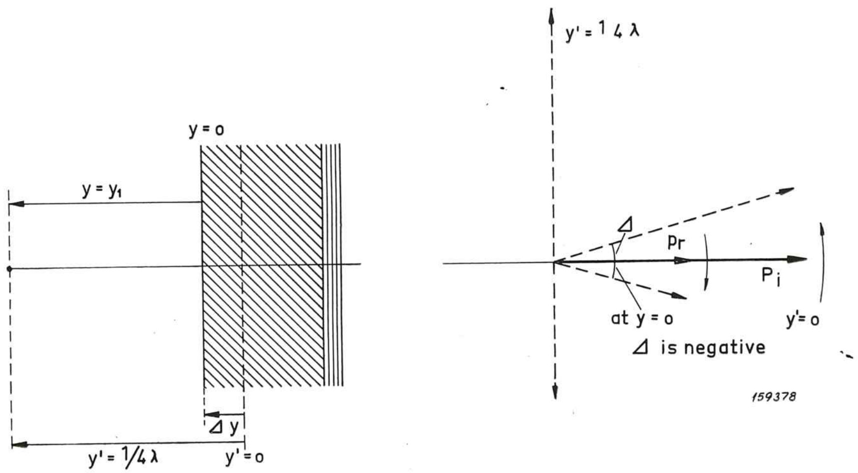

Fig. 9. Vector diagram indicating incident and reflected wave pressures p_i and p_r at fictive plane $y' = 0$, where the reflection appears to occur without any phase jump, and first minimum $y' = \frac{1}{4}\lambda$, $y = y_1$.

For acoustic impedance measurements, the probe tube is adjusted by means of its terminal thread and fixing screw at the microphone end so that the microphone carriage indicates exactly 0 when the probe is just touching the sample. The distance from the front of the sample to the different maxima and minima can then be read off directly. The minima positions are the most accurate to which to adjust the car, and should be used to calculate the phase angle Δ of the the reflection factor $r = |r| \angle \Delta$.
With the first minimum measured at a distance y_1 from the sample surface Δ follows from

$$\Delta = (\frac{y_1}{\lambda/4} - 1)\,\pi \qquad (3)$$

It is advisable for the sake of accuracy to measure the wavelength λ, instead of deriving this magnitude from the frequency set on the oscillator. In those cases where a second minimum can be measured at a distance y_2 (for the big tubes this means for frequencies from about 250 Hz and up), the distance gives half the wavelength, and (3) becomes

$$\Delta = (\frac{2y_1}{y_2 - y_1} - 1)\,\pi \qquad (4)$$

With Δ thus expressed in terms of π, and the absorption coefficient α read off from the scale of Analyzer 2107 or 2112, the resistive and reactive parts of impedance Z, expressed in the unit ϱc or W, i.e. the characteristic impedance of air = 420 kg/m^{2}sec, are found with the aid of graphs 6 or 7.
In graph 6 the intersection of the two circles corresponding to the α and Δ value found in the measurement corresponds with the end point of the vector Z/W drawn from the origin of the orthogonal coordinate system $Z/W = p + jq$. In graph 7 the $|r|$ value ($|r|^2 = 1 - \alpha$) is set out on a radius drawn from the centre of the big circle to the measured Δ value on the circumference. The two orthogonally intersecting circles here also yield directly the resistive and reactive parts of the impedance Z.
Examples of experimental results will be found in the B & K Technical Review, No. 1—1955.

Short Derivation of Formulae used with Standing Wave Measurements.

Formulae (1), (2) and (3) are easily derived with the help of a simple vector diagram (see Fig. 8). We suppose that at $y = 0$ (i.e., the front surface of the sample) the sound pressure of the incident wave is p_i and the sound pressure of the reflected wave

$$p_r = |r| \cdot p_i e^{j\Delta} \qquad (5)$$

At a distance y in front of the sample the incident wave has an angle of lead $2\pi y/\lambda$ (following the convention $p_i(y) = p_i e^{-j\omega x/c}$ where $y = -x$ and $\omega/c = 2\pi/\lambda$). The reflected wave acquires an angle of lag $2\pi y/\lambda$. Leaving the sample surface, therefore, both vectors rotate in the indicated way. With positive argument of the complex reflection coefficient r there will be first a maximum sound pressure in the tube $(1 + |r|)\, p_i$, when both vectors coincide. This occurs at a distance y_o such that $\Delta = 4\, y_o/\lambda$. Then, with both vectors rotated through an additional angle $\pi/2$, the vectors lie in opposite directions, and a minimum, $(1 - |r|)\, p_i$, will be the result. This occurs at a distance y_1 such that $\Delta + \pi = 4\pi y_1/\lambda$, which yields formula (3) directly.
The quotient $\frac{p_{min}}{p_{max}}$ thus follows as

$$n = \frac{p_{max}}{p_{min}} = \frac{1 + |r|}{1 - |r|} \qquad (6)$$

from which follows (1) and (2).

If we define Z as the impedance at the surface of the sample, we have

$$Z = \frac{p_i + p_r}{v_i + v_r} \qquad (7)$$

with v_i and v_r as the particle velocities of the incident and reflected wave. For the incident wave the relation between pressure and particle velocity is $p_i = \varrho c.\, v_i$, for the reflected wave $p_r = -\varrho c.\, v_r$. These, substituted in (7), give

$$\frac{Z}{W} = \frac{1 + r}{1 - r} \qquad (8)$$

This relation between the two complex qualities $r = |r| \cdot \angle \Delta$ and $Z/W = p + jq$ is represented in the two graphs of Figs. 6 and 7. Thus, by measuring the modulus and argument of the reflection factor we can read off directly the resistive and reactive parts of the impedance Z.

True Impedance.

The measurement of n itself is of importance, as it is equal to the "true impedance" N of a material, divided by the characteristic impedance ϱc of air (see ref. 3 p. 66).

The measurement of n follows by moving the microphone car first to a minimum. The meter indication is now regulated by means of the INPUT POTENTIOMETER to a deflection of 0 dB (1). The car is then moved to a maximum, after which n values lying between 1—10 can be read off directly from the meter scale, and n values lying between 10—100 by decreasing the amplifier's gain 20 dB with the METER RANGE switch.

The true impedance of an absorbing material is the impedance at a fictitious plane in the material where the reflection can be assumed to take place. The incident sound wave with pressure p_i penetrates into the material and is reflected at the fictitious plane so that no phase jump occurs, so that we have only $p_r = r \cdot p_i$, where all three quantities are real. This also simplifies the complex equation (8) to

$$\frac{N}{W} = \frac{1 + r}{1 - r},$$

now a relation between real quantities only. As r is real this is also equal to the measured value n according to (6). Thus, the measuring result n yields directly the true impedance $N = n \cdot \varrho c$ without the employment of any graphs, which largely helps to simplify the calculations of many acoustical problems, for example, damping in ducts. The distance $\varDelta y$ between the "reflection plane" and the sample surface follows directly from Fig. 9. $\varDelta y$ + the distance "sample surface to the first minimum", should equal $\frac{1}{4}\lambda$. (The distance y_1 is now smaller than $\frac{1}{4}\lambda$, which gives a negative angle $\varDelta$ for the normal impedance at $y = 0$ according to formula (3). This follows also from Fig. 9b. At $y = 0$ there will be a negative angle $\varDelta$ between p_i and p_r)

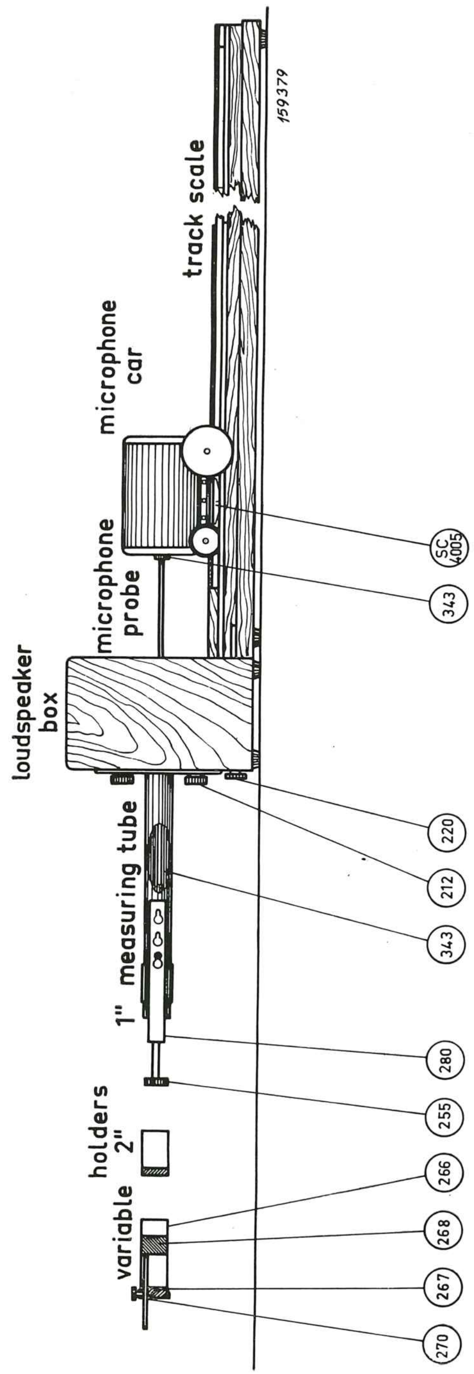

Fig. 10. Part Numbers of the Standing Wave Apparatus Type 4002. 3 cm tube.

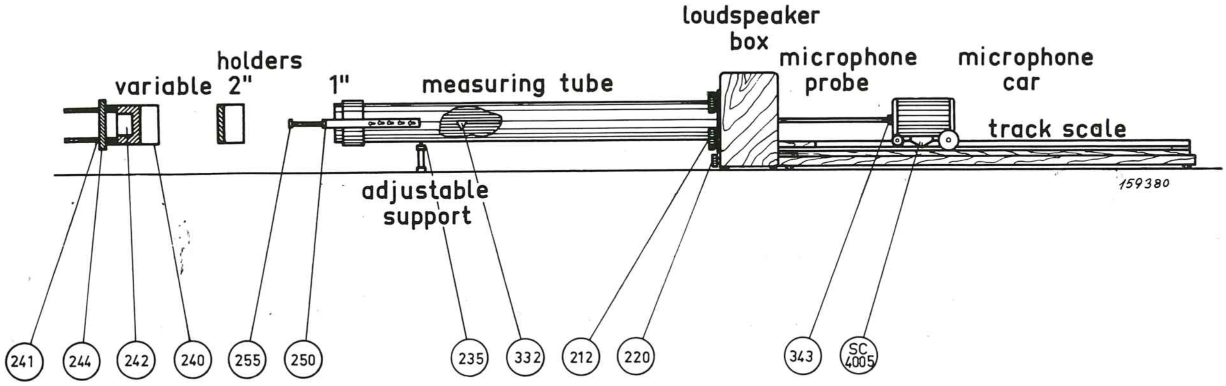

Fig. 11. Part Numbers of the Standing wave Apparatus Type 4002. 10 cm tube.