REPEATABILITY AND REPRODUCEABILITY TESTS OF AIRFLOW RESISTANCE RESULTS OBTAINED ON ITB MEASUREMENT STAND

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ABSTRACT
The paper presents the survey tests for estimation airflow resistance of porous materials that are used for making acoustical applications on a new measurement stand constructed in our laboratory. We have presented the measurement procedure and the results of the tests of results of repeatability and reproduceability.

STATUS OF THE PROBLEM

In porous sound-absorbing materials solid matter is only a portion of the overall volume; the rest consists of cells filled with air. In most cases, they are open on the material's surface and join to form the so-called "pores".

Vibrations of air spread within the pores. Since the pores have very small diameter, the movement of air is suppressed and the vibrations subside proportionally to the friction resistance resulting from considerable influence of air viscosity in pores of small diameter.

The losses of acoustic energy in porous material are in direct proportion to **airflow resistance** of the porous material. Airflow resistance is a parameter, which characterizes the sound-absorbing properties of porous materials, such as the normal incidence sound absorption coefficient and diffuse sound absorption coefficient. There are general quantitative connections between the above-mentioned values, i.e. the estimated airflow resistance can be basis for deriving the absorbing properties of the porous material, i.e. for rough estimate of the shape of frequency characteristics of the diffuse sound absorption coefficient.

In order to determine the relationship between the diffuse sound absorption coefficient and the airflow resistance, it is necessary to conduct a number of measurements of these parameters for the same material.

Until recently, the Acoustic Department was not equipped with a measurement stand that would enable to estimate airflow resistance, which caused the necessity of constructing such stand.

DESIGN AND CONSTRUCTION OF THE MEASUREMENT STAND

The measurement stand to estimation airflow resistance of porous materials consist of:

- measuring vessel (cylindrically shaped sample container), in which the tested sample is placed
- device which generates constant airflow (membrane pump),
- equalizing agent (reducer),
- device for measuring the volume velocity of airflow (airflow meter together with the flow regulating valve -2 units),
- cut-off valve (3 units),
- air filter (2 units),
- control and readout module,
- device for measuring the pressure difference between two unbounded surfaces of the sample (micro-manometer),
- U-tube liquid manometer (safeguarded up to micro-manometer)
- device for measuring the thickness of sample in the test position (measuring device containing electronic caliper gage),
- digital barometric pressure meter,
- digital temperature meter with air measurement sensor.

The measurement diagram and the photograph of the measurement stand for determining the airflow resistance has been annexed as Fig 1.

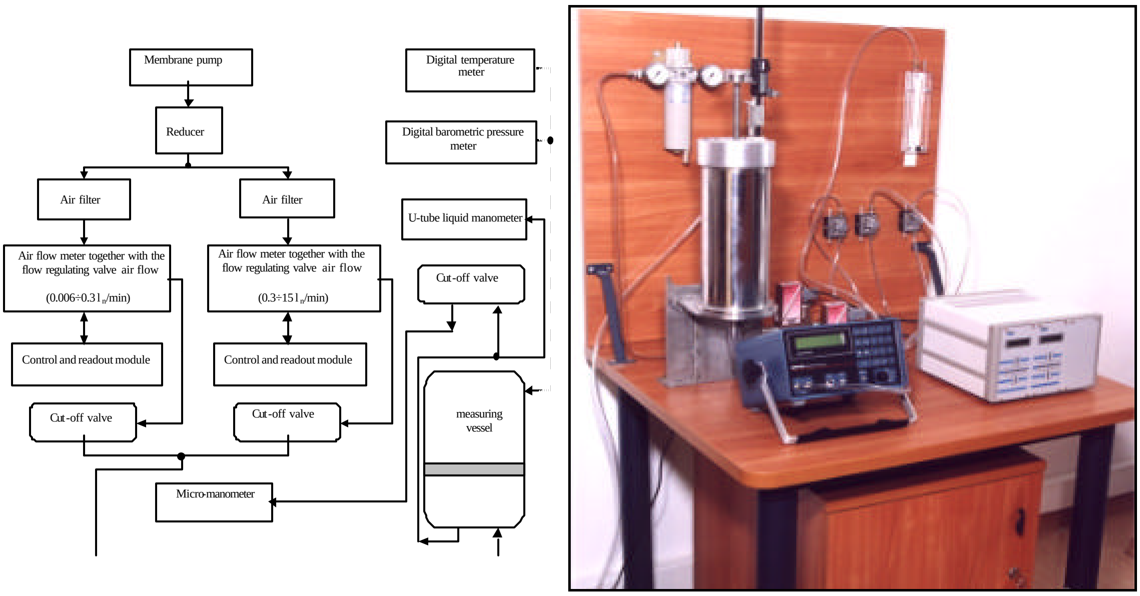

Fig. 1 The structure of the arrangement for measuring the airflow resistance of porous materials used for acoustical applications [1]

TEST MEASUREMENTS OF THE STAND FOR ESTIMATING AIRFLOW RESISTANCE OF POROUS MATERIALS [1]

After the measurement stand has been constructed we perform a series of test measurements. The aim of these measurements was to estimate the measuring abilities of the stand and to form research basis necessary to specify and prepare the measurement procedure.

Preparing The Measurement Procedure

The method applied for the measurements of airflow resistance of porous materials is the **constant airflow method (method A)** described in [3]. The method consists in controlled one-way flow of air through the examined sample, of cylindrical shape, and in measuring the

pressure difference between the two unbounded surfaces of the sample and the sample thickness in the direction of the airflow.
Due to the fact that the unit airflow resistance of many sound-absorbing materials increases to some extent along with the linear velocity of airflow, it should be measured at the lowest possible linear velocity of airflow. The lowest recommended value of linear airflow velocity is $0.5\cdot10^{-3}$m/s (the pressure drop Δp should be measured either directly at u=$0.5\cdot10^{-3}$ m/s, or while gradually decreasing the airflow until the threshold value of the linear airflow velocity). In case of decreasing the airflow, a diagram of unit airflow velocity in the function of linear airflow velocity should made for each respective sample.
The diagram specified above should be used to estimate unit airflow resistance for u=$0.5\cdot10^{-3}$ m/s through graphic averaging or, if necessary, through extrapolation onto this value.
Below we have described the measurement method of estimation airflow resistance.

Measurement Method.
During the estimation of airflow resistance, the following values are measured:
- barometric pressure within the measuring vessel over the tested sample, with the use of digital barometric pressure meter,
- temperature within the measuring vessel over the tested sample, with the use of digital temperature meter with air measurement sensor,
- thickness of the sample in the direction of airflow, with the use of special device accessory to the measuring vessel, equipped with digital caliper gage,
- volume velocity of the airflow through the sample, with the use of the meter together with the control and reading module,
- the difference in pressure on both unbounded surfaces of the sample (taking into account the atmospheric pressure), with the use of differential micromanometer.

Calculation Method
The airflow resistivity "r" is derived from the following relation:

$$r = \frac{R_S}{d} = \frac{R\cdot A}{d} = \frac{\Delta p}{u\cdot d}, Pa\cdot s/m^2$$

The specific airflow resistance "R_s" is derived from the following relation:

$$R_s = r\cdot d = \frac{\Delta p}{u}, Pa\cdot s/m$$

where:
Δp -difference in air pressure on both sides of the sample with respect of the atmospheric pressure, Pa
u -q_v/A -linear of the velocity flow in m/s
d -sample thickness in mm.

Analysis of Uncertainty of the Results of Measurements and Calculations
In order to estimate the uncertainty of the achieved results of measurements and calculations, we have assumed that:
- standard uncertainty of the measurement of **Dp** is u_{Dp}=0.03 Pa
- standard uncertainty of the measurement of **u** is u_u=0.03 mm/s
- standard uncertainty of the measurement of **d** is u_d=0.003 mm

Applying the principle of summing up the variances, with the assumption that the measurements were conducted in accordance with the rules specified in this procedure, the measurement results were influenced only by accidental errors with normal distribution (such assumption is possible for the results obtained with experimental methods), we can perform analysis of extended uncertainty of measurement and calculations of airflow resistance.

Calculating the value of extended uncertainty of estimation of the the airflow resistivity "r" for porous materials is presented in the form of the following relations (for individual result U_{r_i} and for average result U_r :

$$U_{r_i} = 2 \cdot \sqrt{u_1^2(r) + u_2^2(r) + u_3^2(r)} = 2 \cdot \sqrt{\left(\frac{0{,}03}{u \cdot d}\right)^2 + \left(-\frac{0{,}03\Delta p}{u^2 \cdot d}\right)^2 + \left(-\frac{0{,}003\,\Delta p}{u \cdot d^2}\right)^2}\ ,\ \frac{Pa \cdot s}{m^2}$$

$$U_r = 2 \cdot \sqrt{u_1^2(r) + u_2^2(r) + u_3^2(r) + u_4^2(r)} =$$
$$2 \cdot \sqrt{\left(\frac{0{,}03}{u \cdot d}\right)^2 + \left(-\frac{0{,}03\Delta p}{u^2 \cdot d}\right)^2 + \left(-\frac{0{,}003\,\Delta p}{u \cdot d^2}\right)^2 + \left(\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(r_i - \bar{r}\right)^2}\right)^2}\ ,\ \frac{Pa \cdot s}{m^2}$$

Calculating the value of extended uncertainty of estimation of the specific airflow resistance "R_s" for porous materials is presented in the form of the following relations (for individual result U_{Rs_i} and for average result: U_{Rs} :

$$U_{Rs_i} = 2 \cdot \sqrt{u_1^2(R_s) + u_2^2(R_s)} = 2 \cdot \sqrt{\left(\frac{0{,}03}{u}\right)^2 + \left(-\frac{0{,}03\Delta p}{u^2}\right)^2}\ ,\ \frac{Pa \cdot s}{m}$$

$$U_{Rs} = 2 \cdot \sqrt{u_1^2(R_s) + u_2^2(R_s) + u_3^2(R_s)} = 2 \cdot \sqrt{\left(\frac{0{,}03}{u}\right)^2 + \left(-\frac{0{,}03\Delta p}{u^2}\right)^2 + \left(\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(R_{si} - \overline{R_s}\right)^2}\right)^2}\ ,\ \frac{Pa \cdot s}{m}$$

where:
Δp, u, d -as mentioned above.
n -number of measurements

MEASUREMENTS OF THE REPEATABILITY OF THE RESULTS OF AIRFLOW RESISTANCE

For measurements testing the repeatability of the achieved results we have selected the same samples for which the testing measurements were made.

The results presented in the table below reflect the repeatability achieved at the measurement stand for estimating airflow resistance for various porous materials.

Table 1. Results of the examinations of the repeatability of airflow resistance values [1]

Type of material	Measurement number	r, Pa*s/m^2	Ur, Pa*s/m^2	R_s, Pa*s/m	UR_s, Pa*s/m
Mineral wool (density of 40 kg/m^3)	1	5535	6,08	246	0,12
	2	5200	6,14	235	0,12
	3	5415	6,10	242	0,12
	Average	**5383**	277,24	**241**	9,09
	Repeatibility	**388**		**13**	
Mineral wool (density of 145 kg/m^3)	1	21707	9,10	849	0,16
	2	21542	10,35	889	0,16
	3	21200	11,66	921	0,16
	Average	**21483**	422,42	**886**	58,91
	Repeatibility	**591**		**82**	
Glass fiber (density of 60 kg/m^3)	1	33725	7,55	1073	0,18
	2	34524	8,58	1147	0,18
	3	34245	7,10	1058	0,17
	Average	**34165**	662,24	**1093**	77,81
	Repeatibility	**927**		**109**	
Glass fiber (density of 100 kg/m^3)	1	48727	3,32	970	0,17
	2	47812	3,42	970	0,17
	3	47525	3,25	941	0,16
	Average	**48021**	1025,11	**960**	27,34
	Repeatibility	**1435**		**38**	

MEASUREMENTS OF THE REPRODUCEABILITY OF THE RESULTS OF AIRFLOW RESISTANCE

During preparation of tests, Department of Acoustics of ITB have established contact with I.N.C. Corporation Pty. Ltd. South Oakleigh in Australia (D Sc. Marek Kierzkowski) to carry out reproduceability test of airflow resistance. American Standard ***ASTM C-522-87*** and Polish Standard ***PN ISO 9053: 1994*** describe the test procedure for estimation the same parameter - specific airflow resistance "R_s" which has been used as common parameter in the interlaboratory test. Two various porous materials (having different density) like mineral woll and glass fiber used in acoustical adaptations and used as fill in lightweight plasterboard partitions had selected to this test. The same materials have measured on the measurement stands of ITB acc. [3] and I.N.C. acc. [2]. For individual materials both laboratories estimated the unit airflow resistance "R_s". After that repeatibility and reproduceability of achieved results have been calculated. The results obtained from this test are presented in Table 2.

Table 2. The results of repeatibility and reproduceability tests of airflow resistance [1]

Type of material	Laboratory or stand	Number of sample	R_s, Pa*s/m	UR_s, Pa*s/m
Mineral wool (density of 90 kg/m^3)	I.N.C. Corporation Pty. Ltd. South Oakleigh Australia measuring acc. [2]	1	3163	
		2	3285	
		3	3876	
		4	3000	
		5	2910	
		6	3209	
		7	3283	
		8	3303	
		9	3688	
		10	3601	
		11	3092	
		12	3775	
		Average	**3347.1**	
		Repeatibility, r	**656.6**	
	Acoustic Department of ITB Warsaw Poland measuring acc. [3]	1	2872	0,36
		2	2921	0,37
		3	3008	0,38
		4	3055	0,39
		5	3159	0,40
		Average	**3003**	225,72
		Repeatibility, r	**312.8**	
Mineral wool (density of 90 kg/m^3)		**Reproduceability, R**	**656.6**	
Glass fiber (density of 60 kg/m^3)	I.N.C. Corporation Pty. Ltd. South Oakleigh Australia measuring acc. [2]	1	1285	
		2	1064	
		3	1661	
		4	1270	
		5	1380	
		6	1282	
		7	1240	
		8	1185	
		9	1144	
		10	1291	
		11	1347	
		12	1394	
		Average	**1295.3**	
		Repeatibility, r	**414.4**	
	Acoustic Department of ITB Warsaw Poland measuring acc. [3]	1	1157	0,18
		2	1146	0,18
		3	1219	0,19
		4	1232	0,19
		5	1244	0,19
		Average	**1199.6**	89,92
		Repeatibility, r	**124.6**	
Glass fiber (density of 60 kg/m^3)		**Reproduceability, R**	**656.6**	

The values of measurement results have proved good convergence, that means results obtained on measurement stand designed and constructed in Acoustic Department of ITB are credible.

SUMMARY AND CONCLUSIONS

Under the examination arrangement for measuring the airflow resistance of porous materials used for acoustical applications, performed in the Acoustics Department, the following actions were taken:

- mounting the new measurement stand for estimating airflow resistance;
- preparation of the measurement procedure to be followed at estimating the airflow resistance for porous materials used for acoustic applications which can be used in approved acoustic laboratory after all the necessary approvals for the new measurement stand have been obtained;
- carried out measurements of repeatability of the achieved results of the airflow resistance at the measurement stand at the laboratory;
- carried out comparative measurements of the same samples at the new airflow resistance measurement stand and at the laboratory of one of the known laboratory in Australia;

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