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MEASURING ACOUSTIC PROPERTIES OF MATERIALS WITH A MICROFLOWN SENSOR

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Abstract

The issue of noise as an aggravating factor is often a topic to be discussed. This is a consequence of the growth of the human population, coupled with economic growth and the intensive use of sound-generating devices (noise). The paper deals with the use of the Microflown acoustic sensor to research the acoustic properties of materials both indoors and outdoors. It uses its ability to measure reflectivity, absorption or acoustic impedance over a few minutes, broadband, perpendicular to material or at any angle. The practical use of Microflown technology is presented in the measurement of the sound absorption coefficient of materials.
***Keywords**: acoustic, noise, microflown, particle velocity.*

1. INTRODUCTION

The issue of noise as an annoying factor is much discussed topic in the last decades. It is caused by population growth linked with an economy growth and the utilization of the sound producing devices. The significant environmental source of noise is traffic, specifically road transport [5, 6, 10]. Noise effects in urban areas have influence on human health and their well-being, what is the most important reason for minimization of all the forms of noise pollution [1].

Sound is a hearing, produced by small pressure vibration that propagates through the air or an elastic medium. Each sound field is defined by two mutually complementing acoustic properties. By a scalar value that is the acoustic pressure and by a vector value that is the particle velocity. The Microflown is the acoustic sensor that, in addition to the acoustic pressure (common microphones), measures the velocity of particles in an elastic environment. It is utilized for measuring of one-way flows that are used at the particle velocity ranging from 0 Hz [3].

2. THE PRINCIPLE OF OPERATION

The Microflown was used for the first time at the University of Twente in 1994. The first research was oriented to elaborate a design and calibration of the method itself. Later, the cooperation was expanded to the operation of scientific groups and industry, with the aim to develop it.

The research itself includes, in addition to the development of individual applications, also the materials behaviour modelling and their study, which would lead to an improvement of signal-to-noise ratio and also lower energy consumption. This method does not measure a fluctuating air pressure, but the air velocity through two small platinum resistance strips, which are warmed up to temperature of approximately 200 °C. In the dynamics, the movement of gas or liquid particles is called a flow, thus the name Microflown is used. The device is sensitive to the movement of the air particles more than to the pressure. It became available only a few years after it had been invented.

The Microflown is manufactured with the utilization of microtechnology, which is linked to the microelectronics, which started to develop after a transistor had been invented by Shockley in Bell laboratory in 1947.

It was manufactured in three variants: a cantilever type, bridge type and medziprírubový typ. The first manufactured type was the bridge type, where the measuring cables should have been free in the sound field. It is important the cable to have fixed boundaries and also to achieve high frequency and to be as thin as possible. Today, the bridge type (Figure 1) is the most used one. It is able to fulfil the actual demanding requirements. The cables of this sensor are fastened to both sides, what improves the mechanical stability.

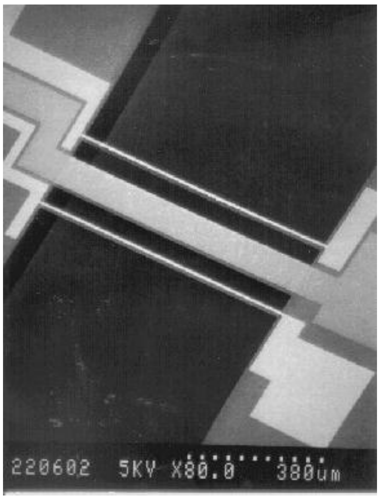

Figure 1. The bridge type of the Microflown [2]

The Microflown technology is suitable to address the acoustic properties of materials in both environments, indoors and outdoors. The reflection factor, absorption or acoustic impedance could be measured within minutes, using the broadband, perpendicular to the material or at any angle. It enables to measure the acoustic pressure and acoustic velocity of particles in-situ on the material surface.

the Microflown sensor is capable to measure the major acoustic parameters ranging from 20 Hz to 10 kHz. In the case of the frequency ranging from 10 - 20 kHz, a special calibration is required. In some specific cases, it is possible to measure within the frequency range from 0,1 to 10 kHz [7].

Maximum natural noise of acoustic pressure level PU and PU of mini probe of the sensor is 10 dB at 100 Hz. For sensors of the particles velocity PU and PU of mini probe there is a maximum of 10 dB at 15 Hz. The intensity of sound and particle velocity are changing in the distance of 5 – 10 cm from radiating surface in order to prevent the errors of reactivity. The particle velocity is the most suitable indicator for a placement of the source itself. The measurement performed in the distance of 1 - 5 cm provides better results [7].

The calibration in the acoustics related to the Microflown is necessary, since it determines the quality of measuring. The aim of the calibration is to determine the output voltage, when a certain acoustic signal is put on the Microflown or microphones. In other words, it is necessary to determine the amplitude reaction.

The calibration Microflown differs from the classical microphones. In the present, the piston is developed, which is placed on the calibrator ball for the Microflown calibration. It is recommended to carry out the calibration every two years. The simplest way how to calibrate is to use the reference particle velocity of the microphone. Due to lack of the sensors of this type, it is necessary to use other measuring device. The most suitable is a pressure microphone, where the problem is focused on the searching for the environment with the specific acoustical impedance. If the acoustical pressure is measured using the particle velocity, it will be calculated by division of this pressure per the specific acoustical impedance. If this impedance is dependent on the place and frequency of the setting measuring, it is possible to obtain many parameters that measure and calculate the particle velocity.

The drawbacks of the Microflown sensors:

- measuring of the complete sound band is time consuming, since it is necessary to change the distance several times,
- it is necessary to carry out the calibration after each change,
- the lower frequencies are hardly to measure (lower than 100 Hz), especially within a reflective environment and
- it is not possible to measure high frequencies (over 10 kHz),
- the measurements carried out using the sensor within near field of sound source are not exact, since the sound intensity is changing along the sensor.

The Microflown consists of two extremely thin wires, the platinum resistors, which acting as the thermal sensors. The diameter of conductors is approximately 0.5 μm, the distance between them is 40 μm and their length is 1 mm. The increase of sensor temperature leads to the resistance increase. If there is particle velocity, both the sensors have common operational temperature, approximately 200°C to 400°C and all the heat will be transferred to the ambient air. In the case that the particle velocity is spreading perpendicular through the wires, the transfer of temperatures changes asymmetrically around the resistors. The difference of the resulting resistance provides the width of band (from 0 Hz to 20 kHz) of the linear signal with an "8" shaped directivity, which is proportional to the particle velocity up to the level of 135 dB. The lower level of noise is ranging from - 10 dB at the band spread of 1 Hz to 1 kHz [2].

If an acoustic wave passes through certain air band, the particles do not vibrate in one place, but move according to the pattern determined by the acoustic wave shape. Depending on the activity of particles, Microflown detects their velocity. It is not possible to perceive high tones as well as it is possible at low tones. The amplitude of the particle movement in the acoustic wave is very small, within the range of 50 nm/s to 1 m/s. The amplitude can be increased at the sensors with correctly selected cover. This phenomenon can be defined as „cover gain". The regular levels of acoustic pressure ranging in intervals around 60 dB. At these levels, the temperature difference of two Microflown sensor differs only in ten thousandth of centigrade degrees. Specific sensing wires are thin – 200 nm (approximately 600 atoms) with width of 10 μm, therefore it is almost impossible to see them with the naked eye (a human hair diameter is 80 nm, thus Microflown sensor is four hundred times thinner than a human hair).

Since the Microflown sensor does not include moving parts, it has no resonances. Is very resistant against extreme ambient conditions, such as high humidity, impurities and high temperatures. It is manufactured in clean premises, which are most commonly utilized in scientific research and have low level of environmental pollutants, such as dust, various microbes, aerosol particles and chemical vapours. This sensor enables to perform measurements in the areas that are usually problematic for traditional sensors.

The Microflown has increased sensitivity in the sources near field. The difference at the measuring of acoustic pressure with the ability of measuring the particle velocity at surface is that the background of acoustic field is suppressed and the acoustic field of surface is more intense. This function is very useful for the methods of localization of noise sources in real environment.

The particle velocity can be detected immediately. It can be measured in 3D space bandwidth (10 Hz - 20 kHz). At one point, you can determine sound intensity, acoustic impedance, and acoustic energy intensity. The sound intensity is related to the sound pressure and particle velocity and quantifies the amount of sound that spreads. The acoustic energy is connected with the quantity of acoustic pressure and particle velocity. The intensity of acoustic energy defines how much energy is included in an acoustic wave, the intensity of sound defines how much acoustic energy is transferred and specific acoustic impedance defines the options of transferring of acoustic energy.

The frequency range for measuring of sound intensity, acoustic pressure and particle velocity using the Microflown sensor depends on the distance from surface and a method of measuring:

- particle velocity: 0,1 - 10 000 Hz,
- intensity: 400 - 10 000 Hz,
- pressure: 20 to 10 000 Hz.

Sound velocity is not influenced by noise and reflections. It provides information about the location of sound source. A minimum distance of reflection area for correct measuring of sound intensity depends on the distance from measured surface in the near area (2 - 3 cm from surface).

A minimum size of sample for good measurement of absorption is 0,3 x 0,3 m, what is suitable for the utilization and comparison with other methods, such as the method with utilization of Kundt tube. The type of material used can determine or decrease a usable frequency range of setting to low frequency and high frequencies, however, according to the definition; it is possible to use any material.

The use of Microflown sensor of particle velocity is available or all the spheres of acoustics, where the particle velocity differs from acoustic pressure. This difference is usually added to the knowledge of sound field or sound source, which is the subject of research. The differences occur especially in the vicinity of sound source or sound field related to directivity. Considering the working principle of Microflown, the medium used would be electrically nonconductive and if possible, with a gas similar to air [4].

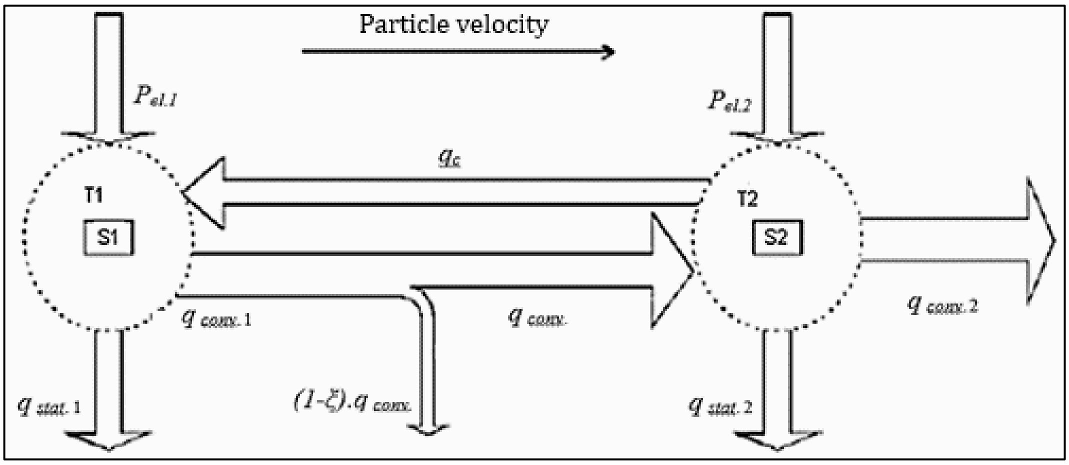

Figure 2. Schematic drawing of the heat flow around a Microflown sensor [4]

On Figure 2, the two rectangles S1 and S1 represent two temperature sensors Microflown. The temperature sensors are implemented as platinum resistors and are powered by electrical current what leads to operational temperature ranging from 200 °C to 300 °C. If the temperature increases, the thermal resistance will also increase. When particle velocity is present, the temperature distribution around resistor is changing. The temperature difference is the measuring gauge for the flow. An electrical current absorbs electric power (Pel.), which heats both temperature sensors. When no particle velocity is present, the temperature of both sensors will rise to approximately 200 °C and all heat will be dissipated into surrounding air (qstat.). When particle velocity is present, a convective heat transfer of both sensors (qconv1&2.) will result in a temperature drop of both sensors. However, the upstream sensor will cause the temperature decrease. A temperature difference will be the result. The temperature difference is proportional to the particle velocity. Not all heat losses of S1, are useful for S2, a certain percentage (ξ) can be lost. This percentage will rise if the sensors are placed further apart from each other. If those sensors are brought together, another phenomenon will become considerably dominant. The particle velocity induced temperature difference will result in a change of thermal flow to the opposite direction. This feedback heat flow will change the sensitivity. Other sensors are placed together, what will increase the effect of heat flow.

3. MANUFACTURING OF MICROFLOWN

The Microflown is manufactured in clean premises, what requires a certain number of working actions. In the beginning, it is important to clean the plates in order to prevent the device contamination. After cleaning, a thin layer of silicon nitride (300 nm) will be places on the plates. This layer fulfils the function of a shield for wet etching and as a carrier for sensor, see Figure 3a. The board will be covered by silicon nitride layer and subsequently it will be placed on a photo-resistant layer. This layer is deposited in a liquid state, since it rotates at a certain speed, where the speed and viscosity of photo-resistant liquid define the thickness of a photo-resist (a light-sensitive plastic material). If the board gets warm as a consequence of hardening, it will be placed and lightened. The lightened profile will be removed by a growth of the photo-resistant layer. The Microflown is a sensor, which is processed by hot wire of the air velocity measuring device, but on the basis of two wires, not one wire, as it is in a classic air velocity measuring device. Those wires are thin and short, produced from silicon nitride and covered by platinum and warmed by direct current up to 300 °C. Their total resistance depends on the temperature [2].

The signal of particle velocity in the perpendicular direction changes the temperature distribution immediately, since the wire will cool down more than the follow-up wire of air flow. The resulting resistance measures the differences in the bridge circuit, which provides the signal proportional to the oscillation velocity.

In order to create sensors and connecting boards, a platinum layer with thickness of 200 nm is needed with the use of so called “sputtering method”. This layer is monitoring one and connecting boards are to make an electrical connection with the board printed circuits. The platinum layer is marked by lift off method (the way of creation of structures from target material on the substrate surface, e.g. on the board surface using the sacrificed material – the photoresist) if the photo-resistant layer is removed and the platinum layer remains, what is shown on Figure 3b. After the platinum layer is completed, the layer of silicon nitride will be etched. The free steel beams are inserted by wet etching. Where the photo-resistant layer is removed, the layer of silicon nitride will also be removed. This principle is shown on Figure 3c. Wet anisotropic etching will create a channel and determine the free cantilever bridges shown on Figure 3d.

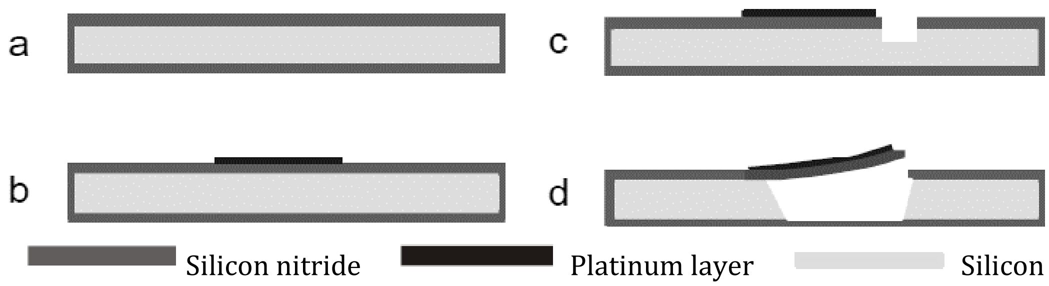

Figure 3. Schematical drawing of particular steps of the Microflown cantilever [4]

The sensors of total acoustic energy are useful for the systems of noise attenuation, since they minimize total density of energy, which can be more effective than a control strategy of noise minimization. As it was stated, the directional information of the particle velocity measuring found the application in the acoustics. Those sensors are also used in the analysis of complicated noise sources, where the mutual experiments are very useful for a characterization of noise sources of machines.

Other applications also include the measurement of impedance and the coefficient of material absorption inside and the measurement of specific acoustical impedance in a tube.

It seems that the sensor of particle velocity, Microflown, has a potential in the measurement of acoustical performance. It is very small, even smaller than standard two microphones of the intensity sensor. It is possible to use it for measuring in the close vicinity at oscillating surfaces. The measuring of sound intensity becomes increasingly popular. In present time, the sound intensity sensor consists of two pressure microphones (p-p sensor). The sensor, which measures the intensity of sound in one direction is very exact measuring device.

4. MEASURING PROBES

Probe PU regular

Probe PU regular consists of two sensors. It is made up of a traditional microphone and the Microflown. The Microflown is a sensor, which directly measures the acoustic particle velocity. Probe PU regular shown on Figure 4 is used for a variety of applications such as the determination of sound intensity, sound absorption, sound leakages. The sensors are applicable to use in reverberant conditions and can be used within closed cavities, such as a car interior [4].

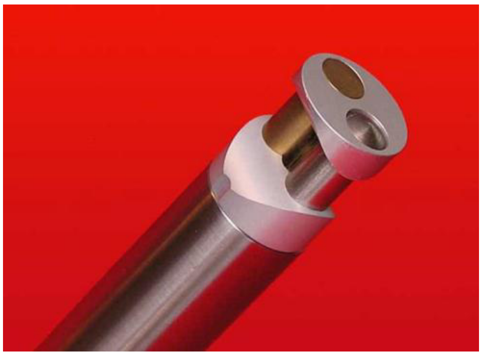

Figure 4. Monitoring probe PU regular [4]

Probe PU mini

The probe PU mini also consists of two types of sensors: a traditional microphone and the Microflown. The probe PU mini - Figure 5 is used for variety of applications. It is mainly used as scattered array for panel noise contribution analysis, free or fixed grid arrays for near field acoustic camera. Also it is used for the determination of sound intensity, sound power or acoustic absorption [4].

Figure 5. Monitoring probe PU mini [4]

Probe USP match

This sensor is one of the state of the art sensor, also called USP sensor – the Ultimated Sound Probe. The tree-dimensional ½ inch USP sensor, Figure 6, consists of three orthogonally placed Microflown sensors and one acoustic pressure microphone. The USP sensor is mainly used when the material size matters. The size of this sensor without its cap is less than 5×5×5 mm^3. It is mainly used as AVS – acoustic vector sensor, it can also be used in the near field for 3D sound intensity, energy, power and acoustic impedance [4].

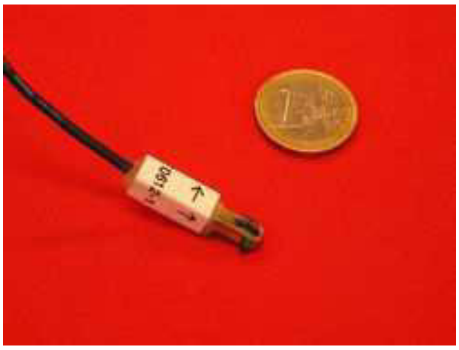

Figure 6. USP match probe [4]

5. THE OPTIONS OF A PRACTICAL UTILIZATION OF THE MICROFLOWN TECHNOLOGY IN MEASURING OF THE MATERIAL NOISE REDUCTION COEFFICIENT

At the methods of a surface impedance of free field we can use the combined sensor of acoustic pressure and particle velocity (PU). Both the sensors are placed in one casing and it is necessary to position them in close vicinity from the material measured. The manual tool for measuring of the noise reduction coefficient by the principle of acoustic pressure and particle velocity measurements, is shown on Figure 7 [3].

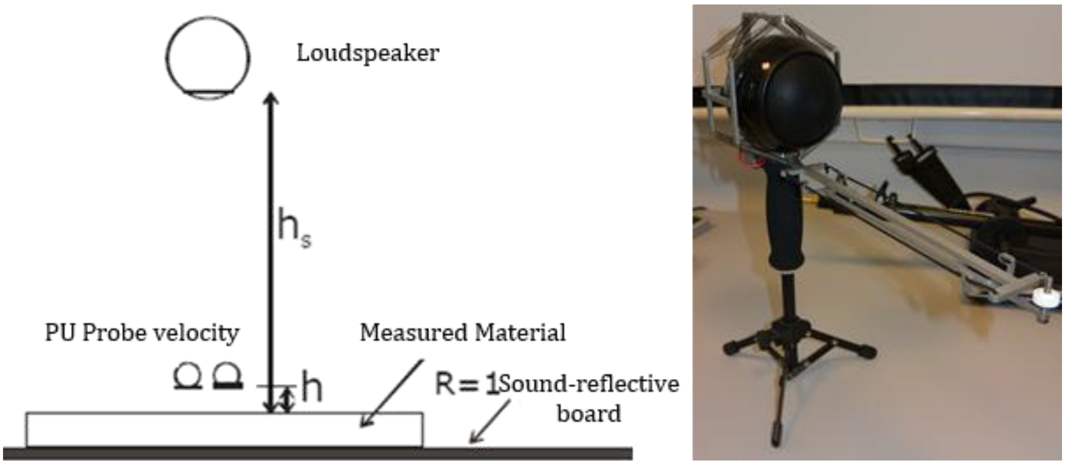

Figure 7. Schematic drawing and demonstration of PU probe and device [9]

The result of those measurements is the frequency dependence of the noise reduction coefficient (α). Figure 8 shows the procedure α of the sample of an acoustic material, which is used as the sound-absorptive covering in the appliances such as washing machines, drying machines or dishwashers. The measured dependence α using the Microflown sensor, which was placed 2.5 cm from the material sample, is graphically compared with mathematically calculated simulation and the measurement carried out using the impedance (Kundt) tube with sensors for measuring of acoustic pressure, thus, using the classical microphones. The measurement in the impedance tube can be, in this case, considered to be the reference one, since this method of measuring and evaluation of the noise reduction coefficient is considered to be more exact.

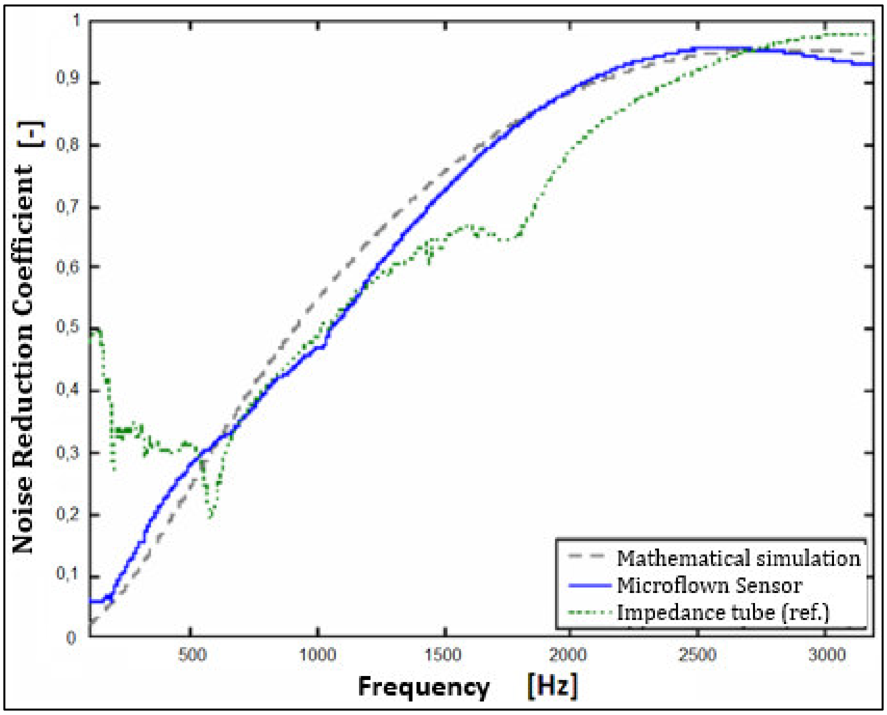

Figure 8. The comparison of results of the noise reduction coefficient [9]

It is obvious from the results that the Microflown technology is from a practical point of view suitable for the determination of the noise reduction coefficient of materials within the frequency range from 300 ÷ 400 Hz to 10 kHz.

Conclusion

The Microflown is a sensor, which creates the new occasions in the sphere or acoustics. The utilization of new acoustical and physical parameters enables to create new applications and improve already existing ones. It is resistant against extreme conditions in surroundings and has no resonances, since it does not contain any moving parts. The Microflown is used mainly in the environment, which is considerably problematic for the classical sensors. The paper also includes the practical section, which deals with a practical utilization of this sensor in measuring of the noise reduction coefficient of materials.

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