ISSN 1392-2114 ULTRAGARSAS, Nr.1(50). 2004.

Absorption of ultrasonic waves in air

A. Vladišauskas, L. Jakevičius

Prof. K.Baršauskas Ultrasound Institute
Kaunas University of Technology

Introduction

Increasing interest in the use of air-coupled ultrasonic measurements, inspection and monitoring is based on the fact that non-contact methods are getting advantage and are promising in new future technologies. At present ultrasonic investigation in the air environment covered many fields of the production and industry. Ultrasonic waves are successfully used to measure distance [1], thickness [2], to generate and receive Lamb waves in the plates [3], in non destructive evaluation [4], to investigate materials [5], for testing of diffusion bonds [6], to investigate surface of objects [7], to measurement of adhesively bonded multi-layer structures [8]. Extensive application of air-coupled ultrasonics in measurements is carried out under different conditions, like temperature, pressure and humidity. As a result, due to influence of temperature, pressure and humidity an ultrasonic velocity and absorption are changed. That has for reaching consequences for measurement inspection and monitoring.

Problems of air-coupled ultrasonics

The air-coupled ultrasonic applications were successfully developing in the past twenty years. However, air-coupled systems have great disadvantages compared with liquid- coupled systems. First, not all power applied to the transducer is transmitted to the medium with the object under investigation, since the impedance mismatch ratio between a standard piezoelectric material and air is considerably greater than in the case of water. The acoustic impedance of water is $1.5*10^6$ kg/m^{3}s, whereas the acoustic impedance of air is 428 kg/m^{3}s. Because of low transmission efficiency between transducer and air, only a small portion of energy is transmitted to the medium. Due to that high insertion losses are obtained. A solution has to be found in odder to provide the receiver with a signal-to-noise ratio large enough for good quality signal processing. The solution of this problem involves the improvement of the impedance matching between the transducer and air by means of matching layers or the use of efficient ultrasonic transducers, the excitation by high voltage spikes of the transmitter or the use of means decrease closes of ultrasonic waves in the coupling medium.

Second, the absorption of ultrasonic waves in air considerably depends on properties of the gas medium: temperature, pressure and humidity. There are many works dedicated to measurement of the acoustic wave absorption in air [9-12]. However, the use of ultrasonic waves in modern technologies requires a deeper analysis of influence of the absorption in the coupling medium or in the measured gas medium.

Calculation and analysis

The purpose of this paper is to calculate the absorption coefficient of ultrasonic waves in air for frequencies which are widely used in the modern technology over a range environmental conditions and frequencies. The frequencies

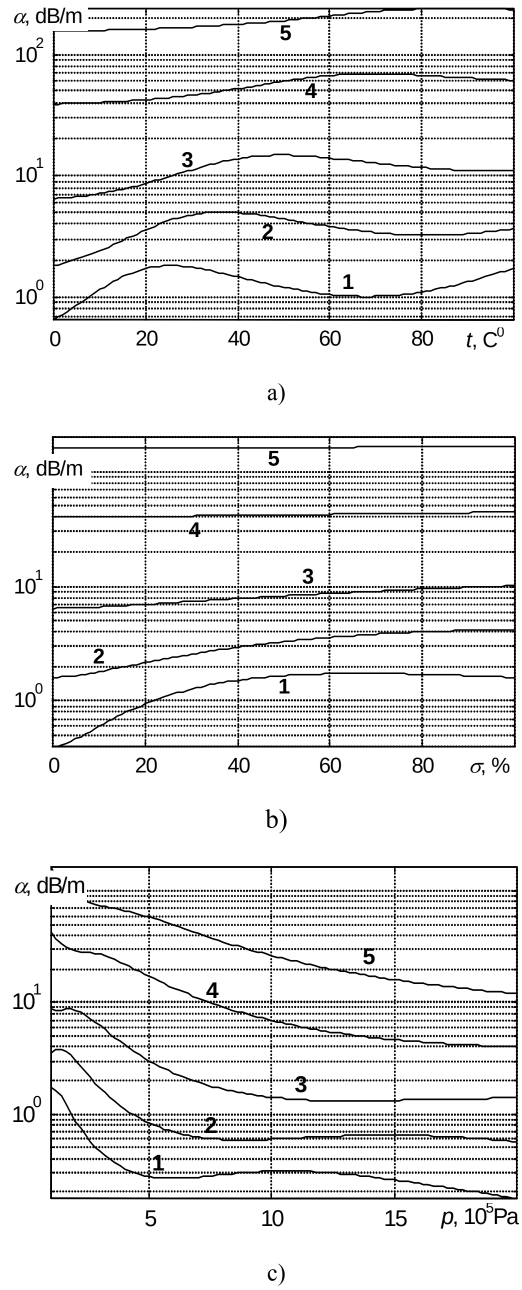


Fig.1. **Dependencies of the ultrasonic absorption coefficient versus temperature (a), humidity (b), pressure (c), when frequency 50kHz (1); 100kHz (2); 200kHz (3); 500kHz (4); 1MHz (5)**

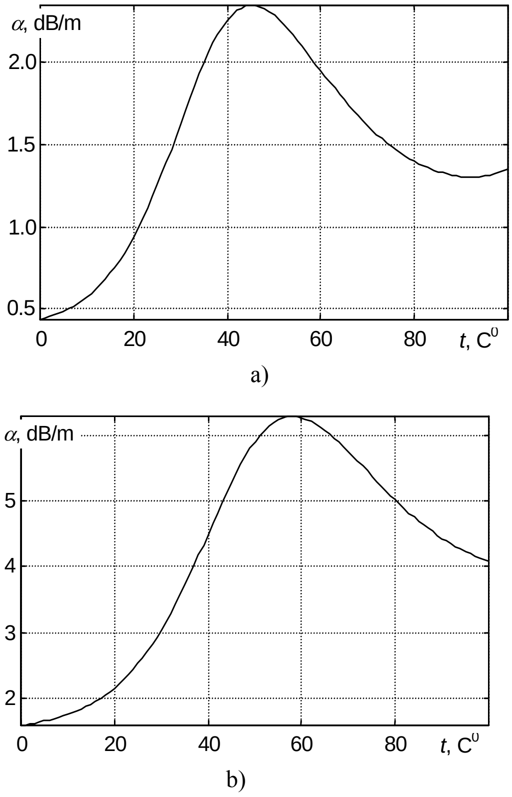


Fig.2. **Dependencies of the ultrasonic absorption coefficient versus temperature at pressure *p*=10^{5}Pa and humidity *σ*=60% at 50 kHz (a) and 100 kHz (b) frequencies**

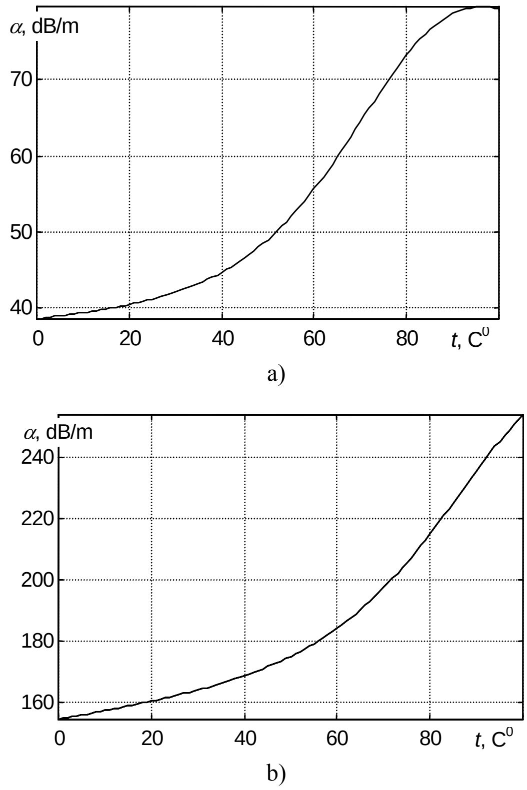


Fig.3. **Dependencies of the ultrasonic absorption coefficient versus temperature at pressure *p*=10^{5}Pa and humidity *σ*=60% at 500 kHz (a) and 1 MHz (b) frequencies**

of ultrasonic waves mostly used in various applications are in the range from 50 kHz to 1.0 MHz. The absorption coefficient of ultrasonic frequencies 50 kHz, 100 kHz, 200 kHz, 500 kHz and 1 MHz were calculated according to ISO 9613 [12]. Dependencies of the ultrasonic absorption coefficient versus temperature, humidity and pressure are shown in Fig 1. Fig.1a shows the dependencies of absorption coefficient versus temperature, when the pressure (*p*=1 atm) and relative humidity (*σ*=60%) are constant. In this ultrasonic frequency range, the dependence of absorption coefficient in air can be divided to two parts: low and high frequencies.

The absorption at low frequencies from 50 kHz to 500 kHz is more complicated, as a maximum value depends on temperature. At high frequencies the absorption of ultrasonic waves in air substantially increases at high temperatures.

For quantitative analysis, the absorption coefficients in air were calculated and presented in the linear scale. The calculation results for low frequencies of ultrasonic waves are presented in Fig.2. Fig. 2a and 2b show that place of maximum is shifted to low temperature range. At the frequency 50 kHz the maximum value of the absorption coefficient comes up to 2.4 dB/m when temperature 45^{0}C. At the frequency 100 kHz the maximum value of the absorption coefficient is 6.3dB/m, when temperature 57^{0}C (Fig.2b). The low frequencies of ultrasonic waves are widely used in the level and distance measurements, object localization, detection and localization of obstacles on the path of a mobile robot and so on. The change of ambient temperatures from 20^{0}C to 40^{0}C degrees at 100 kHz frequency and in the distance 10m gives 23 dB loss of the ultrasonic signals in air.

At high frequencies (500 kHz and 1 MHz) the absorption of ultrasonic waves becomes appreciable (Fig.3). The ultrasonic waves of these frequencies are used in material evaluation and nondestructive testing. In this case there are high losses of the ultrasonic signals in the electroacoustical channel (140-160 dB). Therefore, it is necessary to evaluate the losses in coupling medium (air) and increase of losses due to temperature. For example, the variation of temperature from 20^{0}C to 40^{0}C at 1 MHz frequency gives a loss of ultrasonic signal 8 dB/m.

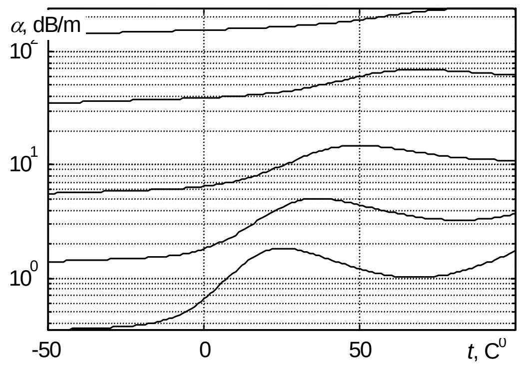
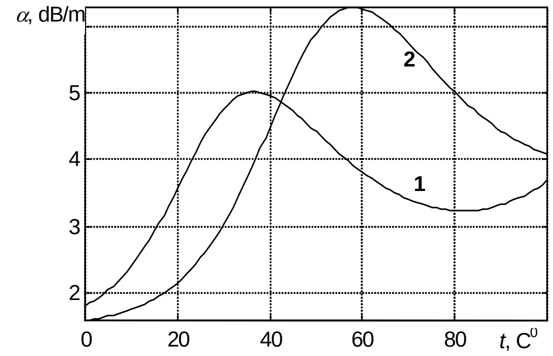
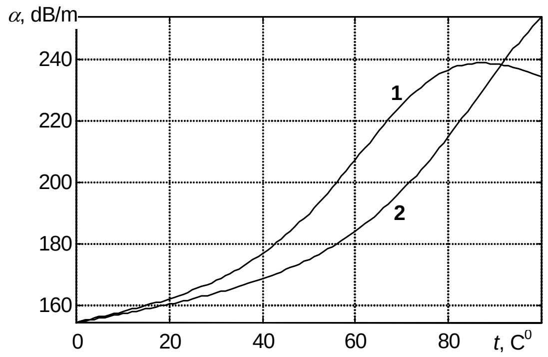


Fig.4. **Dependencies of the ultrasonic absorption coefficient versus negative and positive temperatures at pressure *p*=10^{5}Pa and humidity *σ*=60% at frequencies 50 kHz (1); 100 kHz (2); 200 kHz (3); 500 kHz (4); 1 MHz (5)**



a)



b)

Fig.5. **Dependencies of the ultrasonic absorption coefficient versus temperature at frequencies 100kHz (a) and 1MHz (b), when the humidity of air is 1 – 20%; 2 – 60%**

Variation of temperature from 60^0C to 80^0C at the same frequency gives a losses 18 dB/m.

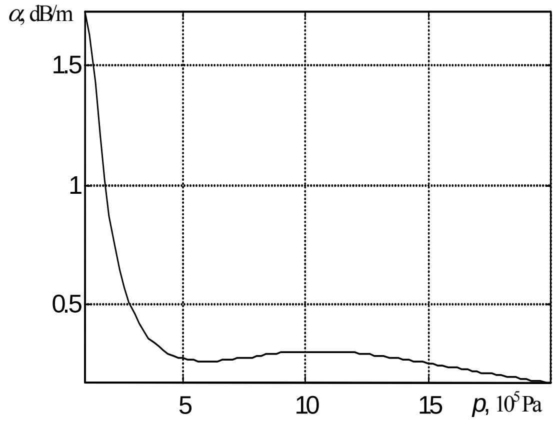
In modern technologies some measurements may be carried out at negative temperatures. The results of calculations from -50^0C are presented in Fig.4. The values of absorption coefficient are lower.

A large number of measurements are carried out at normal atmospheric pressure, but humidity may change. The absorption coefficient in air for different relative humidity values 20% and 60% are calculated and presented in Fig.5. The temperature range is from 0^0C to 100^0C. The results show that the dependencies are complicated.

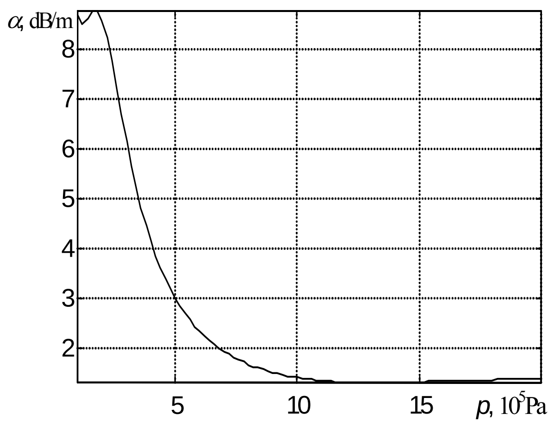
The decreasing of humidity moves a maximum value of the absorption coefficient to lower temperatures. The difference of the maximum value of the absorption coefficient at 20% and 60% humidities depends on temperature and frequency. At the frequency 100 kHz it is 1.2 dB/m, when the temperature increases from 35^0C to 58^0C. However, for high frequency (1 MHz) and temperature about 70^0C, the difference of the absorption coefficient is 30dB/m. In this case it is better to hold the humidity during ultrasonic measurements about 70%.

At wide range of humidity variations the values of the absorption coefficient at low frequency (50kHz and 100kHz) appreciably are affected to 50% of the humidity (Fig.1b, curves 1, 2). At high frequencies absorption increase monotononosly (Fig.1b curves 3, 4, 5).

The pressure in air contributes to decrease of the absorption coefficient (Fig.1c). At low frequencies decreasing of the absorption coefficient considerably depends on only up to $5*10^5$ Pa (Fig.6a and b).



a)



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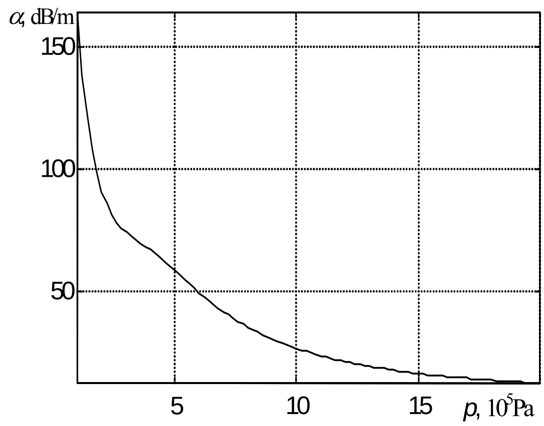

c)

Fig.6. **Dependencies of the ultrasonic absorption coefficient versus pressure at frequencies 50kHz (a); 100kHz (b); 1MHz (c), when temperature t=20^0C, humidity σ=60%**

At high frequencies the absorption coefficient uniformly decreases with the pressure (Fig.6c). Therefore, for reduction of the losses of ultrasonic signal the measurement set up with the increased pressure can be used.

Conclusions

For improvement of possibilities and accuracy of ultrasonic measurement systems dependencies of the ultrasonic waves absorption coefficient versus the temperature, humidity and pressure were calculated.

In the frequency range from 50 kHz to 1 MHz variations of pressure and temperature of environment have the biggest influence on the ultrasonic absorption coefficient.

The ultrasonic absorption coefficient at low frequencies (50 kHz…200 kHz) has the maximum values at some temperatures. At 1 MHz frequency the absorption increases uniformly versus temperature.

The minimum values of the absorption coefficient are observed at negative temperatures.

At low frequencies (50 kHz… 200 kHz) the ultrasonic absorption coefficient considerably changes up to the pressure $5*10^5$Pa.

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A.Vladišauskas, L. Jakevičius

Ultragarso bangų absorbcija ore

Reziumė

Nagrinėjamas temperatūros, drėgmės ir slėgio poveikis ultragarso bangų absorbcijai ore. Pagal ISO 9613-1 standartą apskaičiuotos absorbcijos koeficiento vertės, esant nuo -50 ^{0}C iki 100 ^{0}C temperatūrai, nuo 10^5Pa iki $20*10^5$Pa slėgiui ir nuo 0 iki 100% drėgniui. Parodyta, kokį poveikį šie veiksniai daro ultragarso slopinimo koeficientui, kai dažnis nuo 50 kHz iki 1 MHz. Rezultatams interpretuoti pateiktos absorbcijos koeficiento priklausomybės logaritminėse ir linijinėse diagramose.

Pateikta spaudai 2004 02 25

DOI: 10.5755/j01.u.50.1.8278