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FREQUENCY SELECTION FOR AIR-COUPLLED ULTRASONIC MEASUREMENTS IN CLOSED CHAMBERS

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Abstract

In this work it is shown that a change in attenuation coefficient of ultrasound signal depends on a nature of thermodynamic process when air-coupled ultrasonic measurements are carried out in closed systems. Therefore, for the air-coupled ultrasonic measurements in such systems, it is necessary to choose measurement system parameters in advance according to the thermodynamic process is taking place in the systems.

Key words: attenuation of acoustic signals in air, relative humidity, thermodynamic process

Ultrasonic measurement techniques are used in control of various industrial processes. Time-of-flight measurements of ultrasonic pulse signals take a significant place in these measurements when zero-crossing or zero-level detectors are used [1]. Theory of operation of the detectors is based on the fact that the signal level reaches threshold level of comparator and after that the first zero-crossing after the first threshold interval is fixed in time domain (Fig. 1). This measurement method has the advantage that the zero-crossing detector reaction time does not depend on the incoming signal level, but it is necessary to ensure that comparator of the signal level always reacts on the same signal peak, otherwise the measurements become incorrect. Therefore, there is a need to know the level range of the incoming signal. This is especially important when contactless ultrasonic measurements are carried out in air. Attenuation of ultrasonic signals and hence the incoming signal level depend on air temperature, humidity, pressure and signal frequency during ultrasonic measurements in air [2]. The air parameters can be monitored directly when the measurements are carried out in open spaces. Applying procedure, presented in ISO 9613-1 standard [3], one can estimate ultrasound signal attenuation coefficient in air. However, nowadays there is a need to carry out ultrasonic measurements in closed spaces or small chambers when the air parameters affect the attenuation of ultrasonic signals [4,5]. Under these conditions, it is
difficult to control the air parameters which affect the ultrasound signal attenuation [6]. In closed spaces or chambers, the air parameters are interdependent and their relationships within the system are determined by thermodynamic processes. Therefore, the ultrasound signal attenuation in closed spaces, in air, depends not only on the air parameters, but also on the ongoing thermodynamic process nature in the system [7,8]. However, after in advance assessment of the nature of thermodynamic processes in the closed space, it is sufficient to know the initial values of the air parameters and to measure temperature of the isobaric and isochoric processes or change in volume during isothermal and adiabatic processes. Knowing this data, one can find values of other parameters which affect the ultrasound attenuation in air, and hence evaluate the ultrasound attenuation coefficient in air.

It is relevant to know in advance the level range of incoming signal when ultrasonic measurement technique is used in pulse mode for time-of-flight measurement by zero-crossing detection method. But it is not enough to estimate the ultrasound attenuation coefficient for determination of the level range of incoming signal. However, the level range can be determined from a change in the attenuation coefficient:

\[ \Delta \alpha = 20 \log \left( \frac{p_0}{p} \right) \]

where \( p_0 \) and \( p \) are the incoming acoustic signal pressure amplitudes in the initial conditions and during the measurement, respectively. The smallest \( \Delta \alpha \) ranges are most suitable for practical measurements. Due to that the ultrasound attenuation depends on acoustic signal frequency, in the work \( \Delta \alpha \) is analyzed respectively to the thermodynamic processes of system.

Usually ultrasonic measurements are carried out in spaces with a constant volume where the thermodynamic process is close to isochoric. In the analysis the following initial conditions are introduced: the temperature \( T_0 = 20^\circ C \), the pressure \( p_0 = 100\text{kPa} \), the relative humidity \( \phi_0 = 20\% \). It is estimated that two frequencies, 50kHz and 300kHz, exist where \( \Delta \alpha \) is expected the lowest due to the temperature change (Fig. 2a). These two frequencies tend to split when the air humidity increases. For example, these frequencies become 25kHz and 600kHz, respectively when the relative humidity is \( \phi_0 = 60\% \) (Fig. 2b). Moreover, \( \Delta \alpha \) increases in the frequency range bounded by these two frequencies when the air humidity increases. The maximum change is 1.3dB in the frequency \( f = 100\text{kHz} \) when \( \phi_0 = 20\% \) and it becomes 7dB/m in the frequency 200kHz when \( \phi_0 = 60\% \). Therefore, it is necessary to take into account...
account the relative humidity in air when ultrasonic measurements are carried out during isochoric or close to it process.

However, in some cases the thermodynamic process may obtain features of isobaric process. Corresponding results to the isobaric process are presented in Fig. 3. One can see that $\Delta \alpha$ increases with the temperature increase and it is more pronounced in the higher ultrasonic signal frequencies. Therefore, it is necessary to minimize the ultrasonic wave frequency and to perform the measurements in air with lower humidity.

Fig. 4a shows $\Delta \alpha$ when ultrasonic measurements are carried out in a system with the dominating isothermal thermodynamic process. One can see that due to the system volume change, $\Delta \alpha$ remains lower in the lower frequency range. Moreover, more significant influence of the relative air humidity is observed up to 300kHz on the change in the attenuation coefficient. Therefore, it is necessary to carry out the measurements in the low frequency range and to take into account the relative air humidity influence on the measurement results.

If ultrasonic measurements are carried out in a system where adiabatic or a process close to it is observed, the change trend in the attenuation coefficient is similar to a thermodynamic process (Fig. 4b). In this case $\Delta \alpha$ grows rapidly in lower frequencies, too. Therefore, it is necessary to evaluate and to select all
parameters which have influence on $\Delta\alpha$ during the measurement in the system where the adiabatic process occurs. It is true that a frequency can be found in which $\Delta\alpha$ varies slightly during the adiabatic process. For example, when the relative humidity is $\varphi_0 = 60\%$, this frequency is around 400kHz.

For air-coupled ultrasonic measurements in closed spaces or chambers, it is necessary to determine what type of the thermodynamic process will occur in the system. Knowing the process and the initial measurement conditions, it is possible to select the measurement frequency range and the measurement system settings that the air parameters influence on the measurement results would be minimized.

References