Examination of the impact of tank material on ultrasonic measurements

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Abstract. The article presents the research of the tank material effect on the propagation of the ultrasonic signal. Measurements were made using a prototype measuring card for an ultrasonic tomograph. The device has independent four channels with ultrasonic pulsers, ADC converters, filters, amplifiers, and envelope converters.

1. Introduction
Ultrasound tomography enables the analysis of processes taking place in the research object, also detection of obstacles and various anomalies. The designed measuring system allows for the examination of objects with the use of various types of ultrasonic transducers. Thanks to this type of research, it is possible to correctly understand the features of a given object and to select the appropriate parameters [1-5], methods of image reconstruction [6-19], and provides information on the sound propagation method, transducers directivity, sound speed and amplitude of signals [20-30].

2. Measuring system
The tests were performed by a prototype measuring card for an ultrasonic technique. The measurement card has four independently channels, with build-in high voltage generators with adjustable frequency, adjustable amplitude and adjustable number of pulses.

Parameters available on the display:
- Positive voltage level (0V, +24V, +48V, +72V)
- Negative voltage level (0V, -24V, -48V, -72V)
- The sampling frequency
- Number of samples
- Transducers frequency
- Number of pulses
- Pull to ground after signal generate
- Gain setting of the AD833 chip
- Gain setting of the OPAMP build-in STM32G4
- Settings of the three built-in bandpass filters
- Settings of the signal processing to envelopes
3. Examination of the impact of tank material on ultrasonic measurements

The research on the effect of the material from which the tank is made on ultrasonic measurements was carried out on two types of tanks, acrylic glass and stainless steel. The tanks were filled with water, and ultrasonic transducers were glued to the tank walls, one pair of each type facing each other. The test was simple and was designed to check whether the sound penetrates the inside of the tank or whether it passes the tested object and penetrates through walls of tank. Knowing the speed of sound in the water and the diameter of the tank, we were able to estimate whether the sound reflections appear on analog waveforms in the appropriate time intervals. If not, it would mean that the sound found another faster way to get from one side of the tank to the other.

Figure 1. Acrylic glass measuring tank with a phantom in the center

Figure 2. Transducers mounted on the wall of acrylic glass tank
3.1. Tests with the 1MHz transducers
The first test was performed using highly directional transducers with a resonance frequency of 1MHz in a plexiglass tank. In figure 7 you can see two waveforms. One for the transmitting probe (blue) and one for the receiving probe (pink). The time for the sound to pass from one side of the tank to the other should be about 267 µs. On the other hand, the reflection signal should come twice later (after about 534 µs). It results from the path the signal will travel (400mm) and the speed of sound in the medium in which the sound travelled (for water it is about 1500m/s). In the case of the obtained results - the appearance of the waveforms agrees with the theory. Additionally, you can observe reflections marked in yellow from the phantom walls.

![Figure 3. Transducers mounted on the wall of stainless-steel tank](image)

The second test was performed on a 240mm diameter stainless steel tank with the same phantom in the center. Though the smaller tank and thinner walls, the reflection signal that was obtained was of much worse quality, but was also correct (it should arrive after about 160 µs, while the transmission signal after about 320 µs).
3.2. Tests with the 400kHz transducers
In next case, we used transducers with a lower resonance frequency of 400kHz. The signal obtained was even weaker, but it was mainly due to the construction of the transducers, because they had almost two times smaller diameter.

In the case of the plexiglass tank, the transmission and reflection signals arrived at the expected time intervals, similar to the previously presented tests.
Figure 7. Signal waveforms from the transmitting and receiving 400kHz transducer for a stainless-steel tank with a diameter of 240mm

On the other hand, in the fourth test (Figure 10) for the stainless-steel tank, it was observed that the transmission wave arrived after approximately 80 µs, that is two times faster than expected. Which proves that the sound shortens its path through the walls of the tank. The reflection wave is also much more difficult to analyse. Both waveforms have summed signals passing through the center of the tank and through its walls. Which makes it practically impossible to use these transmitters in measurements on steel tanks in this configuration.

3.3. Tests with the 300kHz transducers

The obtained waveforms from 300kHz transducers are very similar to the waveforms for 400kHz transducers. It also means that the signal captured for the plexiglass tank is as expected.

Figure 8. Signal waveforms from the transmitting and receiving 300kHz transducer for a plexiglass tank with a diameter of 400mm

On the other hand, the transmission and reflection signal for a stainless-steel tank is full of amplitude peeks. That is exactly as in the 400 kHz transducers. That makes further analysis difficult, or even impossible.
3.4. Tests with the 40kHz transducers
The great advantage of the 40kHz transducers with the previously presented is that in measurements on tank with water, their signal does not depend on the place of sticking to the tank. Which means they have a wide propagation angle of the ultrasound wave. The biggest disadvantage, however, is the relatively long wave period, as much as 25 µs. In practice, if the measuring system does not convert signal into the envelope, and measures is only the time from the moment of transmitting the signal to the moment when the first period of the return signal appears, then depending on the set amplitude threshold, the time that such a system will measure will be burdened with an error of +/- 25 µs. Errors of this high degree prevent correct mapping of small objects.

This disadvantage is visible on the waveforms in Figure 13. Despite of the visibility of the reflection from the phantom and the walls of the tank, the amplitude jumps are fade out slower than in the previously shown waveforms for other transducers.
Figure 11. Signal waveforms from the transmitting and receiving 40kHz transducer for a stainless-steel tank with a diameter of 240mm

For the waveforms from a stainless-steel tank, this problem is even more visible after increasing the time constant. In addition, in this case the reflection signal is so difficult to analyse without calculations it is impossible to indicate when the reflection took place from the tank wall.

4. Conclusions

The research clearly confirmed the impact of the material from which the tank is made on ultrasonic measurements. In addition, ultrasonic transducers also have influenced the measurement, their resonant frequency, impedance, size.

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