Mechanical guided waves for fuel level monitoring system

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Abstract: *The mechanical guided waves have a wide range of applications in many types of equipment and devices. The fuel level is an important parameter which needs to be monitored for a vehicle which can be a space vehicle, an aircraft or any other. For this purpose mechanical guided waves can be used as they have several major advantages over any other methods. There are a wide ultrasonic sensors used for this purpose but in the most cases the mechanical waves are traveling through air or fuel for measuring their level. In general the wave propagation through a single media at a time is utilized. The method described in this work uses the propagation of the mechanical guided waves through two different media in the same time. The propagating media is the container wall and the other is the fuel. One of the advantages of this method is the reduction of the measurement errors when the incident angle to the fuel level surface is different from 90 degree. These situations could occur when the fuel tank is tilted or when the fuel surface is not flat. This measurement method will not be affected by these conditions.*

Key Words: *fuel level monitoring, mechanical guided waves, magneto-resistive method, capacitive method*

1. INTRODUCTION

The fuel level is an important parameter for any vehicle and is extremely important especially for space vehicles and aircrafts because their autonomy is an important safety issue. Currently there are a number of classic methods for the fuel level monitoring. From the point of view of the sensor position related to the fuel tank, these methods can be grouped in two main categories: methods using sensors inside the fuel tank and methods using sensors outside the fuel tank.

The first category of methods includes well-known methods such as resistive, magneto-resistive and capacitive methods. One of the first method and maybe the oldest one uses a floating device inside the fuel tank mechanically connected to a variable resistor cursor (resistive method) or to a magnet placed near a magneto-resistive sensor (magneto-resistive method). These methods have the disadvantage of using a moving part inside the fuel tank which is subjected to wear and can provide wrong measurement results due to the partial or total blockage in some high mechanical stress situations determined by high values of accelerations.

Another method from this category uses two electrodes placed close to each other, acting as a capacitor having the fuel or air as dielectric. This method is more robust but the results measurement depends of the dielectric properties of the fuel requiring always keeping the same fuel properties for accurate measurements.

The ultrasound method measures the propagating time of an ultrasound wave through air or through fuel and back to the sensors after reflecting it on the separation surface between fuel and air from the fuel tank. It is also a good and accurate method. The disadvantage of this method is the higher level of error measurement when the fuel tank is tilted and the wave direction is no longer normal to the separation surface.

All these methods require placing the sensor inside the fuel tank which sometimes is not the best option. In the case the fuel tank is already build in some complicate geometries such as a wing fuel tank from the aircraft without first being provided with an internal fuel sensor it would be difficult to add one inside if the fuel tank is sealed or if desired a second measurement system that does not have to interfere with the first fuel monitoring system. In these cases the methods from the second category will be more convenient. Using the sensors outside the fuel tank will have the advantage of much easier inspection or replacement every time when is required than in the case the fuel level sensor is placed inside the fuel tank. A well-known method is to measure the fuel flow in and out of the fuel tank to know at any time the amount of fuel remaining in the tank.

This method could be accurate if the flow rate is high enough for accurate measurements and if the fuel tank has no leaks.

Another method from this category uses piezo-electric transducers and sensors placed on the outside of the fuel tank wall. This method described in this article and uses mechanical guided waves [1] which are propagating through the fuel tank wall and through the fuel near the fuel tank wall. The wave propagating properties of the fuel tank wall being different from the fuel, the received wave parameters will depend of the fuel quantity from the area between the wave generating transducer and the receiver.

Despite the frequency of these waves are in the ultrasonic range this measurement method is not affected by the fuel tank orientation in space if sensors are placed on both opposite walls of the fuel tank.

The advantage of this method is due to the fact that the angle of incidence of the wave to the fuel surface doesn’t change with the fuel tank orientation as in other methods which uses ultrasonic waves for the fuel level monitoring.

2. METHOD DESCRIPTION

To determine the thickness of the fuel between the transmitter and the receiver this method uses a pair of transmitter-receivers.

Simple schematics of the method setup is shown in Figure 1. Mechanical oscillations produced by the transmitting device will propagate as mechanical waves through the fuel tank wall and fuel.

So the initial waves generated by the transmitter will split in two sets of waves which are propagating through two different media in parallel, one will propagate through the fuel tank wall and the another through the fuel as in figure 2.

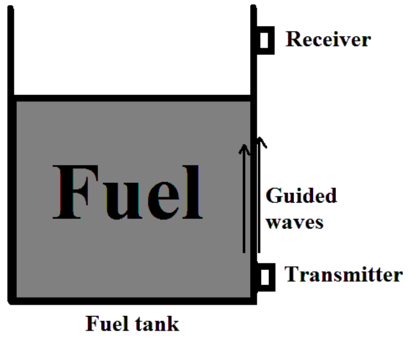

Figure 1. Schematics of the method setup

When the waves which are propagating through the fuel will reach the upper surface of the fuel, most of them will be reflected but the rest of them will be transmitted further into the fuel tank wall where they will combine with the existing waves which are propagating through the wall from the transmitter.

The shape of the received signal will depend on the path length of the waves which has passed through the fuel.

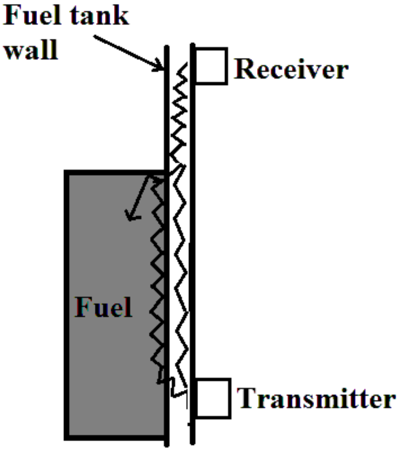

Figure 2. Propagating waves through the system

Both transmitting and receiver devices are Piezoelectric Wafers Active Sensors (PWAS) [2] and they will be attached to the external surface of the fuel tank wall.

Of course they can be attached also to the inner surface of the fuel tank but this will be more difficult in some situation where there isn't possible to gain access inside of the fuel tank.

During the wave propagation there will be reflections on the interface between the fuel tank and fuel media which will diminish the wave energy but it will still remain enough energy to be sensed by the PWAS receiver.

The measurement method consists in measuring the amplitude of the received wave for a range of frequencies and comparing the amplitude-frequency dependence for both symmetric S0 and antisymmetric A0 modes [3], [4] with an existing set of characteristics obtained for different fuel levels during the calibration procedure.

The calibration procedure consists in measuring the amplitude-frequency characteristics and recording them for a number of values of the fuel level.

3. EXPERIMENTAL SETUP

For a preliminary laboratory test of this method an aluminum plate 250 x 750 mm size and 2.5mm thick was utilized with two sets of PWAS devices attached as in Figure 3.

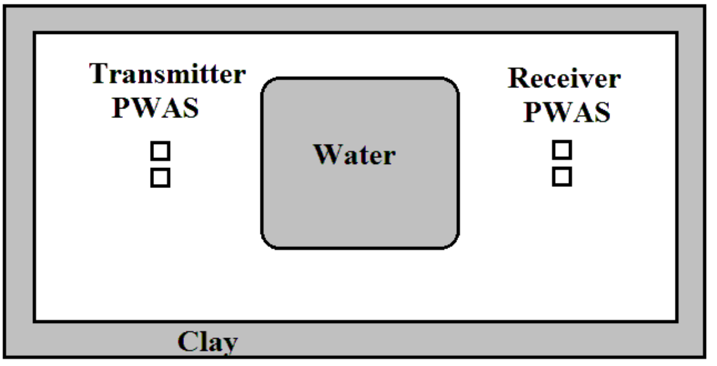

Figure 3. Experimental setup aluminum plate

The aluminum plate is padded with clay on its entire perimeter 50mm wide on both sides for absorbing any mechanical guided waves through the plate before to be reflected on the plate boundaries.

The PWAS devices are produced by STEMiNC [5] and have a square shape of 7mm size as shown in Figure 4.

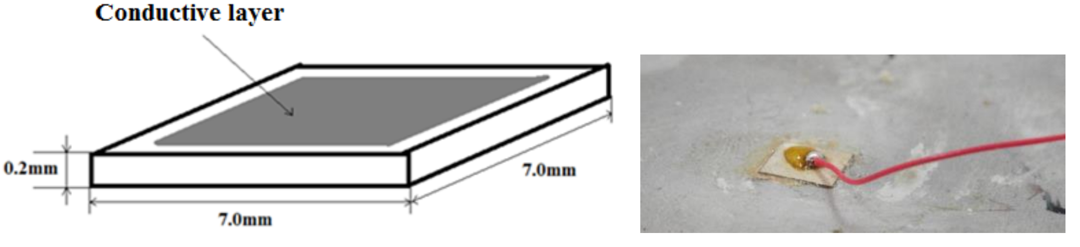

Figure 4. The PWAS devices used for the experiment

In the middle of the plate, in the space between the two sets of PWAS devices an amount of water has been placed to cover about 60% of this space.

A view of the aluminum plate without water is shown in Figure 5.

Figure 5. Experimental setup aluminum plate view

4. EXPERIMENTAL PROCEDURE

The experimental procedure has two main stages. In the first stage the procedure is carried out without water on the aluminum plate, followed by the second stage where the same measurement procedure is used but adding water on the aluminum plate in the space between the two sets of PWAS devices.

For studying the effect of the presence of a liquid on the mechanical guided waves, sinusoidal electric signal having Hanning modulation type [2,3] has been applied to one of the PWAS devices from the left hand side of the plate, having the amplitude of 20Vpp and frequency in the 30 – 460 kHz waveform generator, see Fig.6.

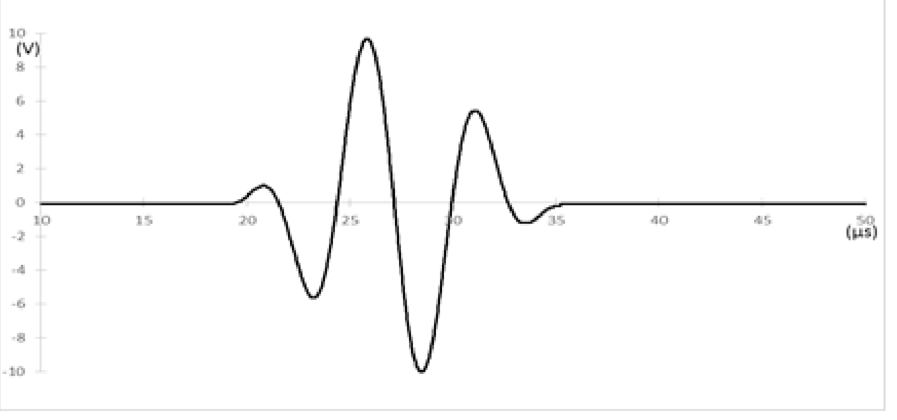

Figure 6. Hanning window modulation sinusoidal pulse [6]

The received signal from a PWAS device from the other set placed towards the other end of the plate has been collected and applied to a TDS5034B digital oscilloscope for analyzing and measuring its parameters.

As first step the signal has been analyzed for identifying the A0 antisymmetric and S0 symmetric modes [5] as shown in Figure 7.

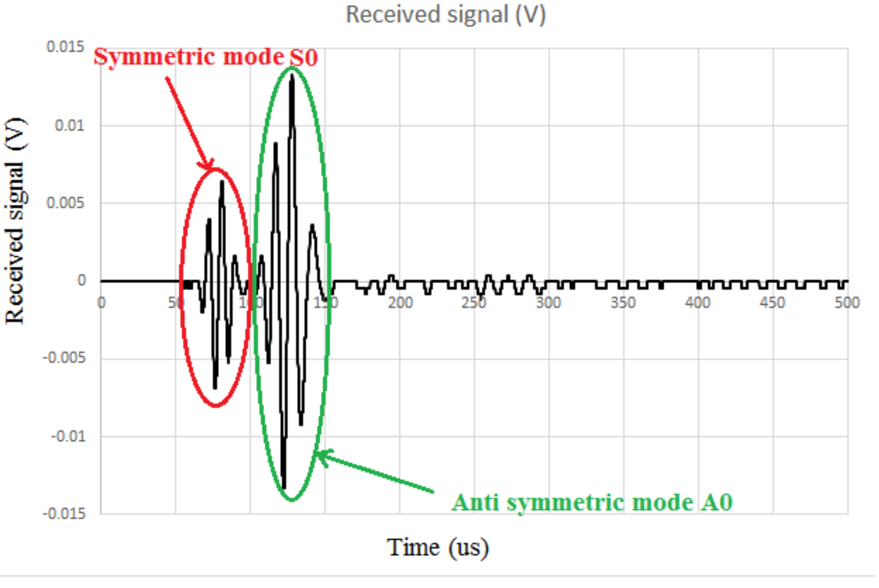

Figure 7. Antisymmetric A0 and symmetric S0 modes [7]

Once the two modes of wave propagation have been identified the next step is to measure the maximum amplitudes corresponding to each of these modes as shown in Figure 8 and to record its value together with the corresponding frequency of the signal.

This procedure has been repeated for each value of the frequency in the testing range until completing the whole frequency range.

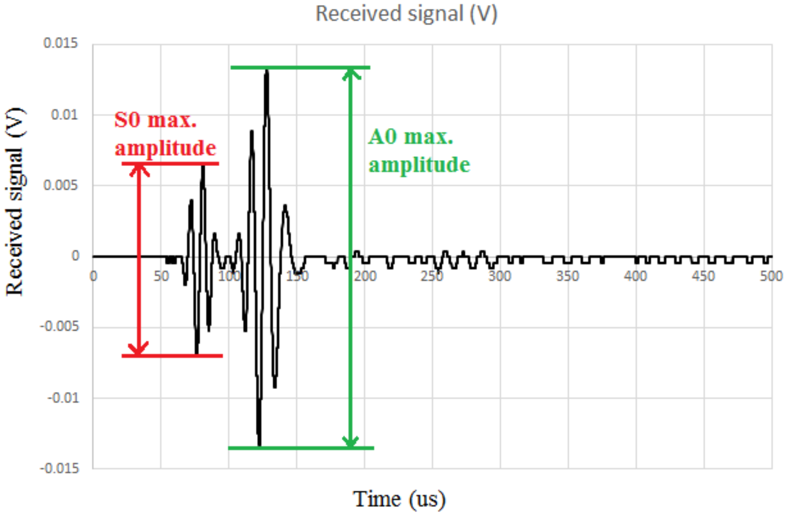

Figure 8. Measuring A0 and symmetric S0 modes signal maximum amplitudes

During the test performed with water, the water position was kept still for avoiding variations of the received signal amplitudes.

5. EXPERIMENTAL RESULTS

The dependence of the amplitude of the received signal with signal frequency has been plotted in Figure 9 for both wave propagation modes and for both cases with and without water on the plate.

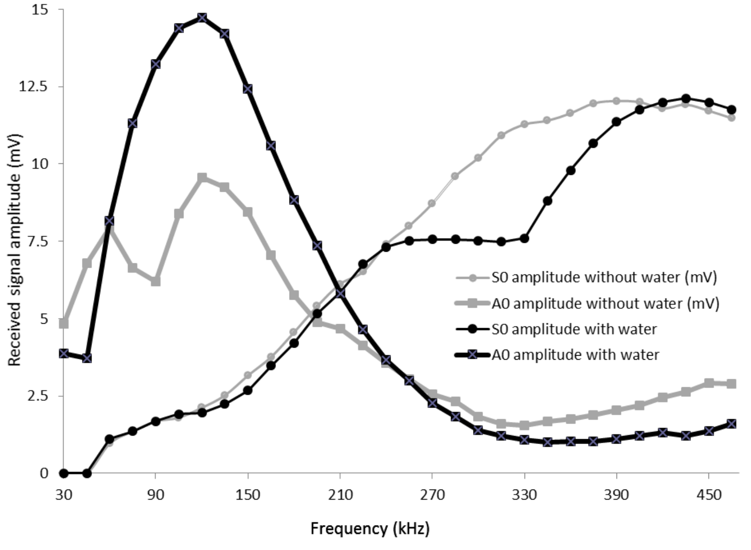

Figure 9. Dependence of the amplitude of the received signal with frequency

As can be seen from Figure 9, there are some frequency ranges where there isn't big differences between the two cases with and without water as for S0 propagating mode in 30 250 kHz frequency range and for A0 propagating mode in 240 – 280 kHz frequency range.

On the remaining of the frequency ranges, there is a clear difference between the received signal amplitudes for the two cases, so the water presence on the plate surface has a clear influence on the received signal amplitude.

In general the presence of water on the aluminum plate surface increases the amplitude of the received signal for A0 propagating mode for 50 – 240 kHz frequency range and has as result a reduction of the signal amplitude for 240 – 460 kHz for both wave propagating modes.

6. DISCUSSIONS AND CONCLUSIONS

From these preliminary results, there has been found a clear influence of the water presence in the space between the transmitting and receiver PWAS devices on the received signal amplitude. The dependence of the signal amplitude variation with the area of the water surface for different plate material and for different liquid types needs to be further investigated.

An important role in the wave propagating is played by the fuel tank wall because guided wave transducers are placed on this wall. The most important parameter of the fuel tank material is the wave attenuation factor.

If this material has strong mechanical wave absorbing properties, the received signal will be too low to be measured if the distance between the transmitter and receiver is exceeding a critical value.

In this case, a solution would be the use of a single transmitter and multiple receivers which would increase the measurement accuracy because the mechanical waves propagate mainly through fuel.

So this situation doesn't seem to create difficulties for the fuel level measurement. The only situation that may not be so convenient would be if the fuel has strong mechanical wave absorption properties, as small differences in amplitude of the received signal in the cases with or without fuel in contact with the fuel tank wall are to be expected.

Of course as future work, the next step will be to attach PWAS devices on a real fuel tank used in aircrafts or other vehicles and perform tests for different thickness of the fuel tank wall.

The calibration procedure of the measurement system could be automatically performed using a flowmeter and in this way calibrating for near continuous variation of the fuel level in the fuel tank.

The experimental results make this method promising for fuel monitoring systems especially in the cases where it is not possible to have access inside a fuel tank and the measurement needs to be performed from the outside.

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