Preliminary study of the influence of low temperatures on tuning conditions of the Lamb waves in aluminium plates for Structure Health Monitoring

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Abstract: *The method of Lamb waves to detect defects in aerospace structures is already known in research environments for its benefits, using an inexpensive equipment. The major benefits are: accurate determination of location and size of the defects in material and the fact that it is a non destructive method. For experiments are used aluminum plates that are willing piezoelectric exciters as follows: a piezoelectric actuator placed on a point on the plate will excite that point and the signal will be received by a piezoelectric receiver placed on another point from the plate. By interpreting the shape, phase and amplitude of the received signal we can determine the shape and location of the defect. The excitation signal frequency should be previously known by determining the amplitude in a frequency band set between 10-800 kHz, for the plate without defects, which is called the tuning procedure. Due to the fact that the structures will work also on flight condition temperature as on high altitude or in space, it is neccesary to check how these extremelly low temperatures influence the defect detection. For this purpose the first step is to determine how the temperature variation affects the tunning results. As preliminary study the first step of the tunning procedure has been performed at different low temperature down to -* 70^0C.

Key Words: *guided waves, PWAS, structure health monitoring, low temperatures*

1. INTRODUCTION

For the health monitoring of the structures (SHM) guided wave transmission process are used for the advantage of having small energy loss even at their transfer through large structures. It is also possible to detect internal faults at various depths within the material structure. The analysis of these waves in plates has been performed by Horace Lamb who published his results for the first time in 1917, [1]. The mode of propagation of these waves is divided into two categories: symmetric propagation by changing the thickness of the plate and antisymmetric propagation by bending the plate [2]. The most common modes used for SHM are fundamental symmetric S0 modes that dominate in the range 130- 400 kHz and antisymmetric A0 modes prevailing in the range 20-130 kHz. Because signals generated by defects are generally weak and hard to identify, it is necessary to determine the optimal frequency for each mode of fundamental propagation [3]. The procedure was performed using a clean aluminum plate [4], identical (same size with the same physical and mechanical properties) as the plate having defects, using two PWAS transducers, (Piezoelectric Wafer Active Sensors) the first as a transmitter and the second as receiver. To distinguish the two modes of propagation, in the case of defective plates it is necessary to determine the optimal frequency for both the propagation symmetric mode and anti-symmetric propagation mode [5]. In the case of low temperatures the experiment is carried out in a climate chamber where the plates are subjected to extreme conditions of temperature close to flight condition from high altitudes or from outer space conditions.

2. EXPERIMENT LAYOUT

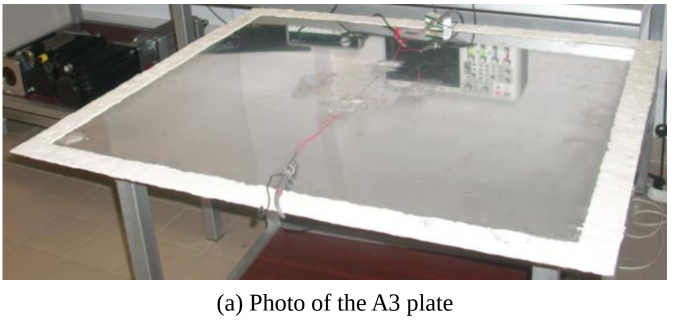
2.1 Experimental system

For the experiment a rectangular plate, of 1000 x 850 mm, which is referred to as A3, without defects, with five PWAS transducers stuck on it was utilized. The PWAS device has deposited two conductive layers on both sides [6] which are connected to the signal generator. The bottom conductive layer is connected to the aluminum plate by applying pressure on it. This plate is connected to the ground point (GND) of the signal generator. The top layer of PWAS is connected to the generator also through a shielded electric wire having the shield connected to the ground point too, as shown in Figs. 1 (a) and (b).

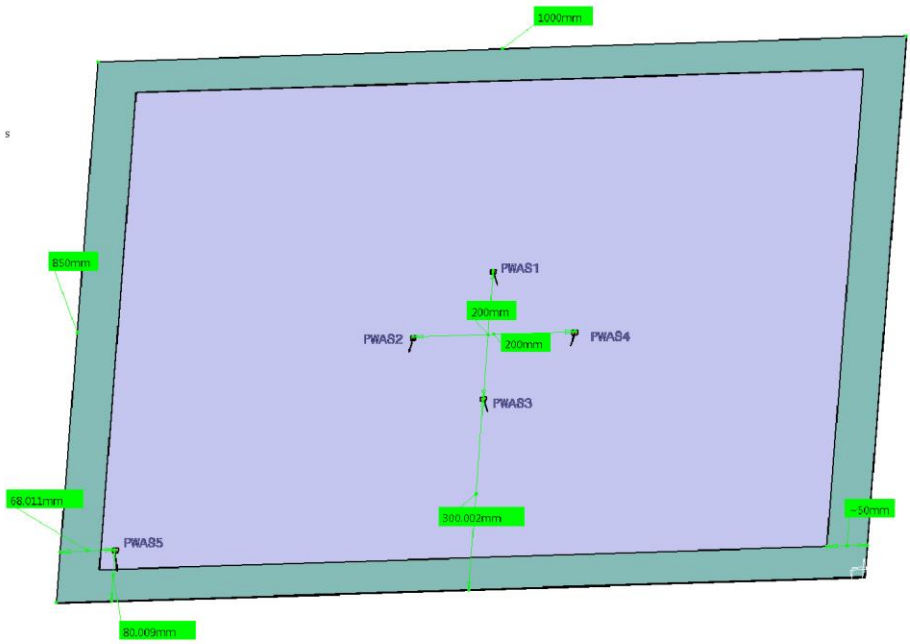
(a) PWAS dimensions (b) detailed view of the attached PWAS to the plate

Fig. 1 PWAS details

For clear transmitted signals, the distance between the transmitter PWAS and the receiver PWAS must to be large enough to eliminate overlapping of fundamental signals and also the signal accuracy has to be high enough. On the edges of the aluminum plate A3 was attached a strip of modeling clay, with 50 mm width and thickness of 5 mm on both sides. Its role is to absorb the reflected waves. Five PWAS transducers were glued on the experimentation plate, located at a specified distance between them were stuck on the experimentation plate, as shown in Fig. 2. This experiment serves to a better understanding of the Lamb wave propagation for different plate's temperatures and it is a first step to determine the configuration for the aerospace structures. In this configuration one PWAS is the transmitter and the other one is the receiver, the Lamb waves crossing the plate from one to the other. If wave reflections or other oscillations are absorbed or attenuated, a clear signal could be obtained without any additional oscillations.



(a) Photo of the A3 plate



(b) Drawing of the A3 plate

Fig. 2 The layout of PWAS on the test plate A3

The excitation signal is applied to one of the PWAS which acts as a transmitter. This signal is a sinusoidal tone burst having an amplitude of 20V peak to peak with a Hanning window amplitude modulation [7].

This signal includes 3 periods and is generated by an Agilent 33120A, a signal generator (Fig. 3).

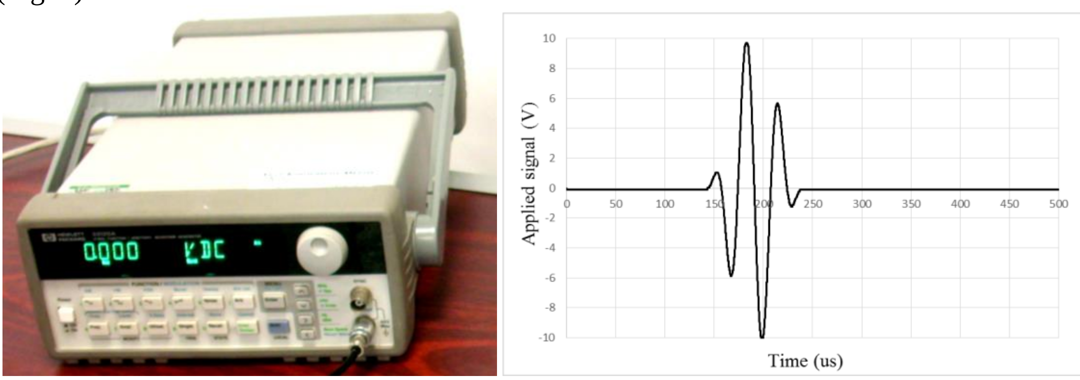


Fig. 3 Hewlett Packard 33120A arbitrary waveform generator and the applied signal shape

This modulation type provides a gradual excitation with progressive amplitudes of the mechanical structures.

Each PWAS, transmitter and receiver are connected to an oscilloscope probe that collects the electrical signal and applies it to the oscilloscope's inputs for monitoring data signals.

This applied signal is used also as a reference signal for the data processing. All these probes are connected to an Agilent DSO-X 3034 digital storage oscilloscope which performs the data acquisition (see Fig. 4).

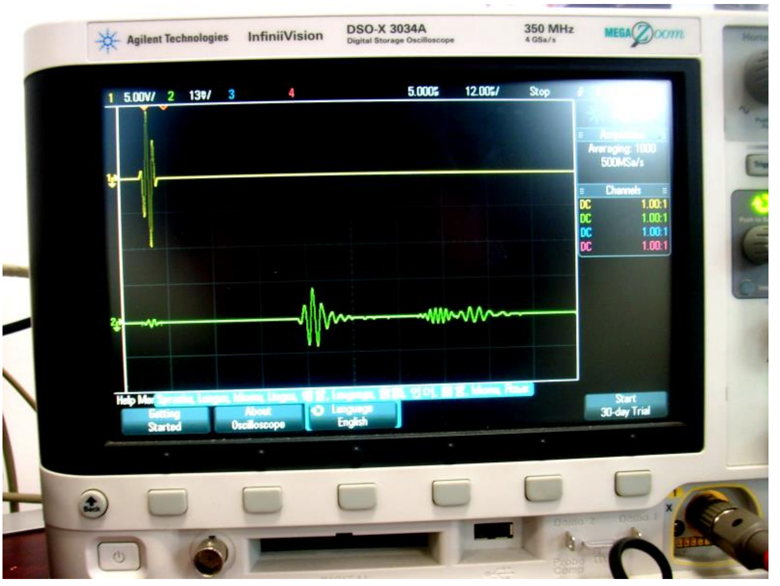


Fig. 4 Agilent DSO-X 3034A digital storage oscilloscope screen

These data is forwarded via USB to a PC where they are displayed and stored on a hard drive. The entire system is presented in figure 5.

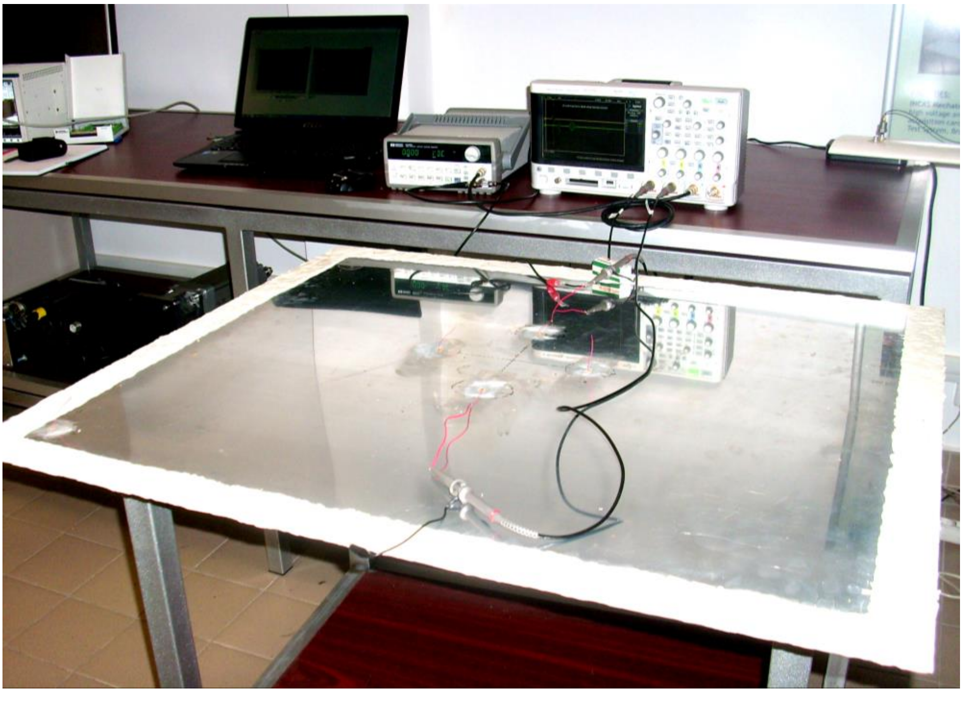


Fig. 5 The experimental system setup for tuning Lamb waves

A Labview code software running on a PC stores the digital data and provides the control of the arbitrary waveform generation and the digital storage oscilloscope.
This PC is connected via USB and RS232C ports to the other devices as shown in Fig. 6.

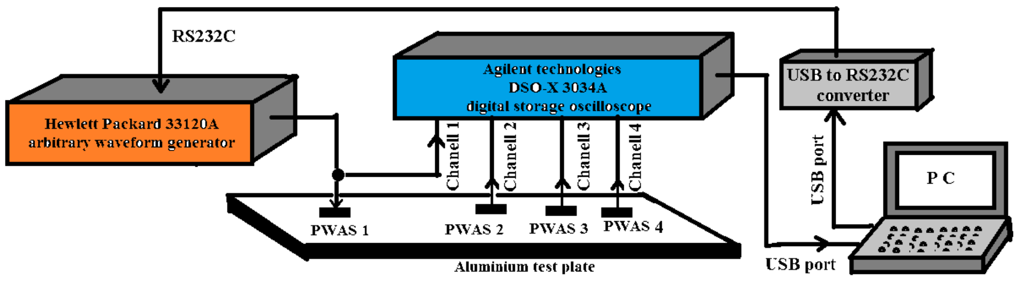


Fig. 6 Block diagram of the acquisition system

The data processing is made offline using a second Labview program which loads the previously acquired data, displays the signal shapes and stores the results into another data file. For testing on different lower temperatures, the testing plate was introduced in a climatic test chamber. For minimizing the heat transfer, the plate was suspended by four wires inside the climatic chamber. After that, the air from inside was removed.

This climate chamber is a ILKA IV STBV-1000 model and it is usually used to test electronic and hydraulic aircraft equipment in conditions of temperature and pressure similar to the flight conditions. The climatic chamber can operate in several modes with selectable screens having a touchscreen operator console (see Figs. 7 and 8).

Fig. 7 ILKA IV STBV-1000 climatic chamber

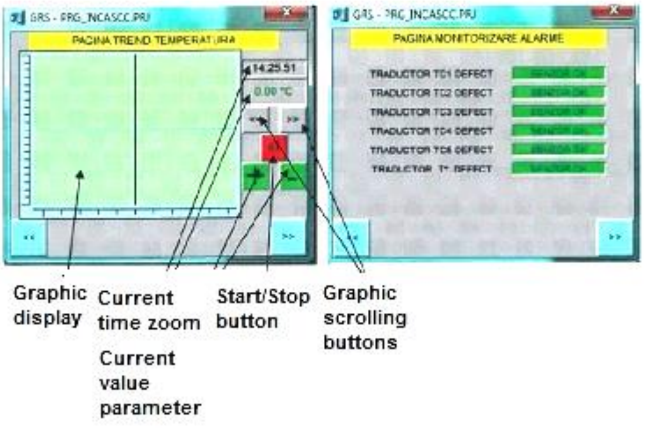


Fig. 8 Screens with operating conditions and monitor commands

The main characteristics are:

- temperature range: −200ºC … 200ºC, associated with depression, reaching 1.5 Torr in 30 min,
- volume 1m^3 (length: 1.16 m, width: 1.0 m, height: 0.84 m),
- operating temperatures achieved in the following intervals: from 20°C to −150°C, in 15 min, from 20°C to 200°C in 40 min.

The cryogenic temperatures values and the time of reaching them depend on the volume of micro enclosure in the climate chamber and of the refrigerant (carbon dioxide, liquid nitrogen, etc.). For this experiment liquid nitrogen was used as cooling agent which allows reaching temperatures values down to -196^{0}C. Due to the A3 plate size, the heat transfer was high and the lowest temperature could go down to -100^{0}C.

During the experiment the mentioned temperature was not reached due to the limited amount of liquid nitrogen in the reservoir of installation.

2.2 The procedure

At the PWAS1 actuator a frequency of the carrier signal varying in the range of 1-80 kHz, with 10 kHz step was applied. Simultaneously the waveforms received from the other PWAS devices were acquired as well as the signal transmitted; the value was averaged for 1,000 acquisitions. Averaging waveforms aimed to reduce the noise. The temperature varied in the range of -10 ... -70^{0}C. As it can be noticed in Fig. 9, the received signal contains two types of oscillations: S0, which represents the propagation symmetric basic mode and A0, which corresponds to the propagation antisymmetric basic mode [8].

Because the maximum amplitude for each mode of propagation varies with frequency, it is necessary to repeat the procedure for measuring the maximum amplitude for each frequency in the whole range of scans. The purpose of experimentation is to search two extreme situations, primarily when the maximum amplitude S0 is the highest compared with the maximum amplitude A0, and secondly, when the maximum amplitude A0 prevails.

By calculating the maximum values of reports S0/ A0 and A0/ S0 we will determine the optimum tuning frequency values for each frequency [9].

Preliminary tests of the signal for the tunning procedure were performed within this experiment. For this purpose the whole frequency range was scanned at each temperature and then the signal shape and amplitude were compared.

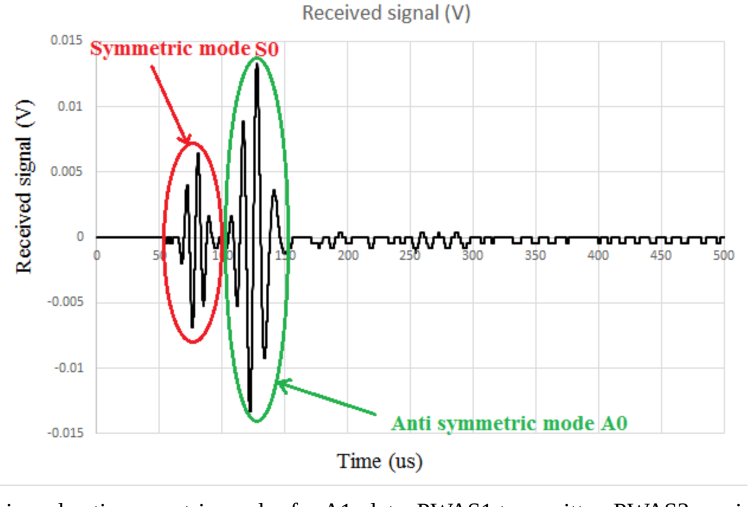
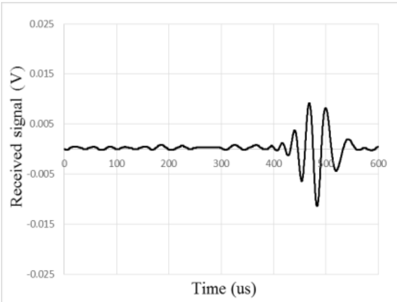


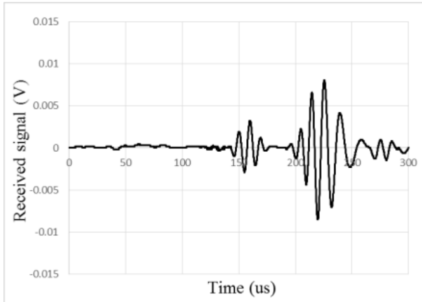
Fig. 9 Symmetric and anti-symmetric modes for A1 plate, PWAS1 transmitter, PWAS3 receiver at 100 KHz

3. EXPERIMENTAL RESULTS

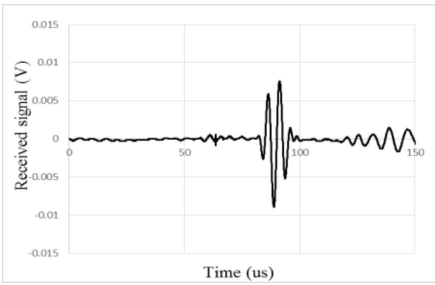
From all the acquired waveforms on all frequencies we have selected a few results on three frequencies: 30, 90 and 180 KHz at three temperatures: -70ºC, -40°C and -10^{0}C for showing how the signal shapes changes with frequency and temperature. Figures 10, 11 and 12 show these waveforms acquired using PWAS2 as a transmitter and PWAS3 as a receiver for different frequencies and temperatures.



(a) 30 KHz

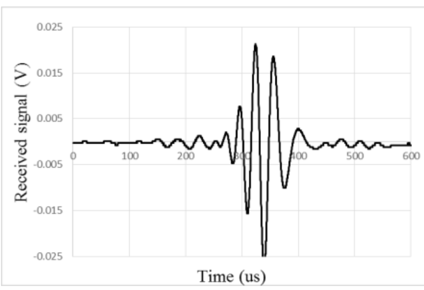


(b) 90KHz

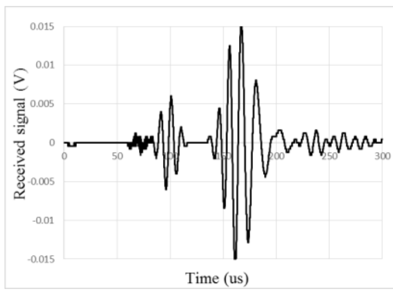


(c) 180KHz

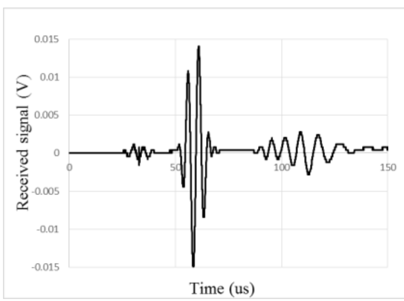
Fig. 10 Comparison of the received signal for different frequencies for A3 plate at -70^{0}C



(a) 30 KHz

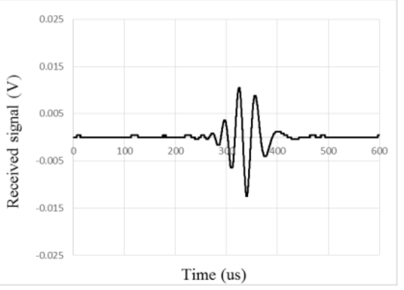


(b) 90KHz

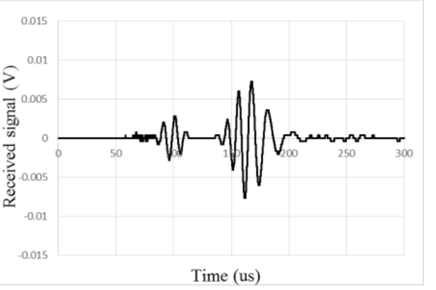


(c) 180KHz

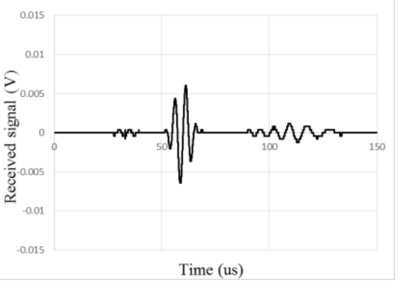
Fig. 11 Comparison of the received signal for different frequencies for A3 plate at -40^{0}C



(a) 30 KHz



(b) 90KHz



(c) 180KHz

Fig. 12 Comparison of the received signal for different frequencies for A3 plate at -10^{0}C

The fundamental anti symmetric propagation mode A0 is dominant at 30 KHz (Figures 10.a, 11.a and 12.a) and it is still biger than the fundamental symmetric propagating mode S0 at 90 KHz, (Figures 10.b, 11b and 12.b) and becomes much smaller at higher frequencies where the fundamental S0 mode becomes dominant (Figures 10.c, 11.c and 12.c) for all temperatures.

The signals corresponding to S0 and A0 modes can be clearly distinguished in all cases at different temperatures and different frequencies than the dominant ones. The first group of tiny oscillations from Figures 11.b,c and 12.b,c is not produced by any mechanical oscillations. It is an electrical perturbation collected by the receiver wire conection as radio waves coming from the transmitting wire. The connection wires act as transmitting and receving aerials. This happens due to the high level of the maximum amplitude of the injected signal (20V peak to peak) and to the high sensitivity of the measurement system on the inputs (5mV).

Comparing these results, for all three frequencies and for both S0 and A0 propagation modes, a clear difference of the signal maximum amplitude at different temperatures can be noticed. It is smaller at -10ºC and -70^{0}C than at -40^{0}C. For 90KHz the A0/S0 ratio with temperature also varies but not as high as the maximum aplitude of the S0 and A0 modes.

4. CONCLUSIONS AND FUTURE WORK DIRECTIONS

From this preliminary study of the influence of the temperature on the Lamb wave propagation it was found that the temperature clearly influences the peak amplitude of these waves, so is important to perform further studies if the temperature will influence also the dominant S0 and A0 modes frequencies values.

Due to the temperature differences which can occur between different areas of the plate, especially at low temperatures it was necessary to wait enough time for reaching the thermal equilibrium before proceeding to the frequency scan.

These results demonstrate that there is a clear change with temperature of the wave amplitude which is due to several combined causes. One of them is changing of mechanical characteristics of the plate which has influence on the waves absorption. Another reason for these variations could be the change of the electro-mechanical characteristics of the PWAS devices with temperature. For establishing the contribution of each of these causes it will be useful to perform further studies of the PWAS devices without considering the aluminum plate behavior in relation to temperature.

A future direction will be to study how the S0 and A0 dominant mode frequency varies with temperature and to establish a clear dependence of the signal maximum amplitude on these two frequencies by the temperature.

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