Preliminary results of ultrasonic output at different applied contact forces to the transducer

A Justen[1], E W J Santos[1], M L Mosqueira[1], T C Dourado[1], S A Miqueletti1, R P B Costa-Felix[1]

[1] Laboratory of Ultrasound (LABUS), Directory of Scientific and Industrial Metrology (DIMCI), National Institute of Metrology, Quality, and Technology (INMETRO), Duque de Caxias – RJ, Brazil,

alexjusten46@gmail.com; tcdourado@inmetro.gov.br

Abstract. Ultrasound is a powerful tool for medical and industrial applications. However, with the new opportunities of Industry 4.0, it is natural that measurement protocols become increasingly robust. In contact ultrasound measurements, no studies were identified that systematically evaluated the effect of the transducer contact force on the ultrasonic properties. Therefore, this work aims to study the state of the art of this problem and present a measurement protocol in which it is planned to evaluate the ultrasonic behaviour under different contact forces experimentally. The quantities of interest will be the ultrasonic velocity and the relative amplitude of the propagation signal. Three carbon steel samples were selected for the evaluation planned in this preliminary study. This material was chosen mainly because of its low roughness, which should mean greater control over variations in said properties. For these measurements, the pulse-echo method, with a 5 MHz central frequency transducer, was used to evaluate the amplitudes of the three first reflections and the longitudinal velocity measured from the transit times of the amplitude peaks of the referred reflections. The results of this study will indicate that the increase in the contact force improves the coupling conditions, increasing the amplitude of the ultrasonic signal available to the system. Regarding propagation time, no changes in propagation speed were identified.

1 Introduction

Ultrasound (US) is a robust technique that excels not only in medical applications but also in nondestructive testing for industrial applications[1][2][3][4][5]. US has proved to be a robust tool that allows the qualitative and quantitative evaluation of several materials, from compounds of a more heterogeneous nature to the usually homogeneous ones typical of metals.

However, in contact ultrasound field applications, there is a gap in the actual impact on ultrasonic properties due to the use of different contact forces imposed on the transducers.

In quality inspection, ultrasound is mainly applied to detect material defects such as metals, wood, concrete, rocks, etc. The process involves the generation of high-frequency sound waves that are transmitted through the material in question. Ultrasound measures the time sound waves travel through the material and return to the transducer. Based on this time, it is possible to detect the presence of defects such as cracks, porosity, or internal flaws [2]

This work deals with ultrasonic properties related to the longitudinal velocity and the received amplitude of the acoustic signals after propagating in a medium. The effects identified with the variation of the contact force imposed between the transducer and the face of the sample of interest will be evaluated. Notably, these measurements will be made later with improvements in the established protocol and following the requirements set in the GUM [6] for calculating the respective measurement uncertainties. The direct and indirect effects will be verified along with the variations of the contact force against the defined properties.

2 Materials and methods

2.1 Theoretical background

Is it possible to evaluate the effect of different contact forces imposed on ultrasonic transducers on acoustic properties and their respective measurement uncertainties? So far, no studies have been identified that evaluated, through a metrological approach, the relationship between the longitudinal ultrasonic velocity properties and the measured amplitude against different contact forces or for various frequencies. Thus, the main objective of this work is to define a measurement protocol that allows us to analyze the relationship between different contact forces imposed on ultrasonic transducers and the variation of the mentioned acoustic properties.

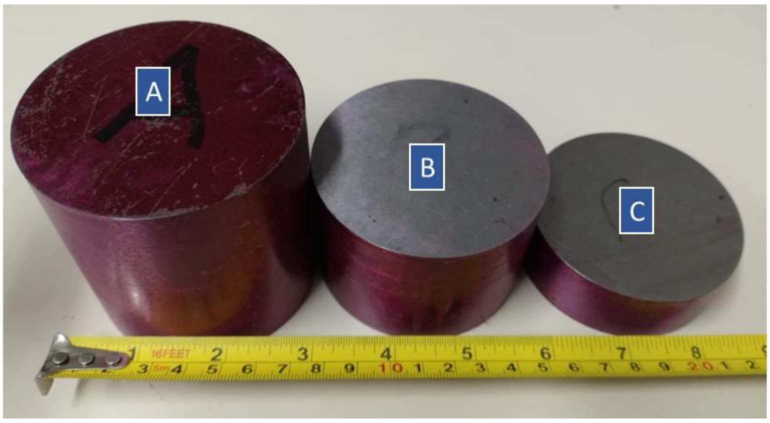
High sensitivity in data detection is the most significant advantage of the test employing ultrasound in the wood [7], as it stimulates the detection of internal discontinuities and characteristics on materials due to their speed and attenuation occurring directly to the microstructure characteristics of the analyzed fabric. When manually evaluating the force factor applied to the transducers, it was observed that they generated errors in obtaining the ultrasound test results on the wooden parts. The applied force directly influences the propagation energy of the ultrasonic pulse in the test [7].

Factors such as the characteristics of the transducer, dimensions of the microstructure of the material to be tested, dimensions of the part to be tested, transducer frequency, transducer's compression force, humidity, density, and temperature directly affect wave propagation [8][9][10]. Researchers studied the effects of ultrasound tests on wood in the laboratory of nondestructive tests at Unicamp, Brazil [9]. It was found that the choice of the ideal coupling material also interferes with the propagation of waves and should be based on the type of material tested, thus minimising physical processes such as refraction, attenuation, and wave dispersion.

2.2 Tested specimens

Three carbon steel specimens of around 76 mm in diameter and lengths of 25 mm, 40 mm, and 76 mm were analyzed to validate this work's experimental proposal, see Figure 1. In future studies, four types of materials will be selected: concrete, wood, rock, and aluminium. A family (same source matrix) with three specimens was chosen for each material. For concrete, the samples to be studied will be 10 cm x 20 cm with different compressive strengths (f_{ck}). For the rock, the samples will be 4 cm x 7.5 cm, 6 cm x 7.5 cm, and 8 cm x 7.5 cm. Wood samples will be 40 mm, 60 mm, and 80 mm.

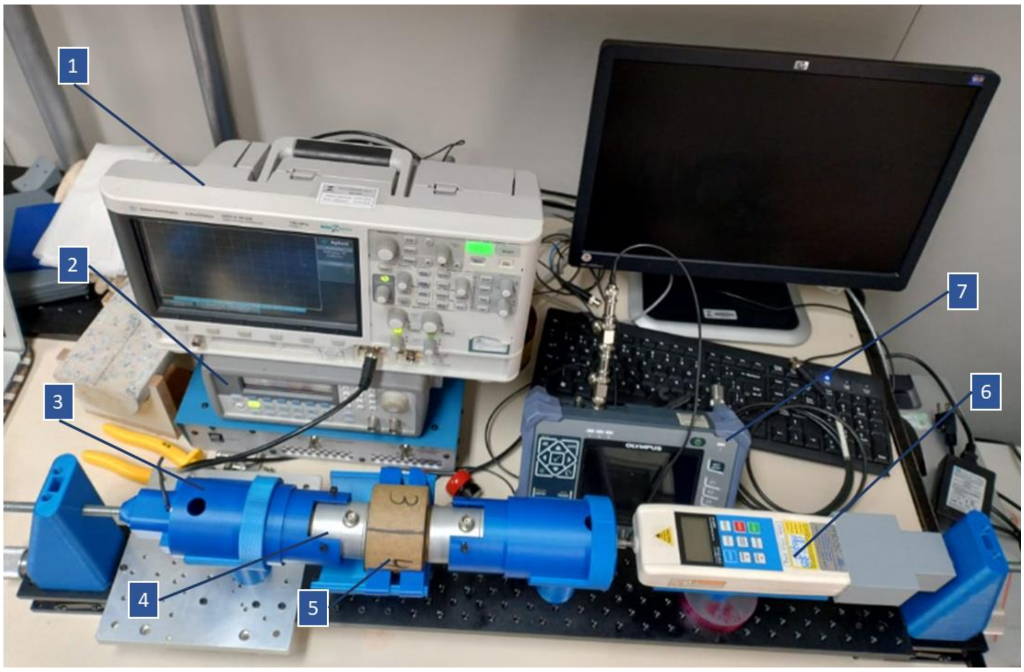
Figure 1. Carbon steel specimens.



2.3 Ultrasonic measuring system

The measurement setup comprises: a longitudinal wave transducer (model 58-E4800, **Figure 2**, four) with a centre frequency of 24 kHz model 58-E0046/30, 54 kHz (model 58-E4800, **Figure 2**, four) and 150 kHz 58-E0046/33, both (CONTROLS, Italy); an oscilloscope model DSO-X 3012A (Agilent, USA, **Figure 2**, one); an EPOCH 600 ultrasonic flaw detector (Olympus-NDT, USA), a signal generator model 33250A (Agilent, USA, **Figure 2**, seven). A digital force gauge model IP-500 (IMPAC, Brazil, **Figure 2**, six) provided the force monitoring applied on the linear system (**Figure 2**, three).

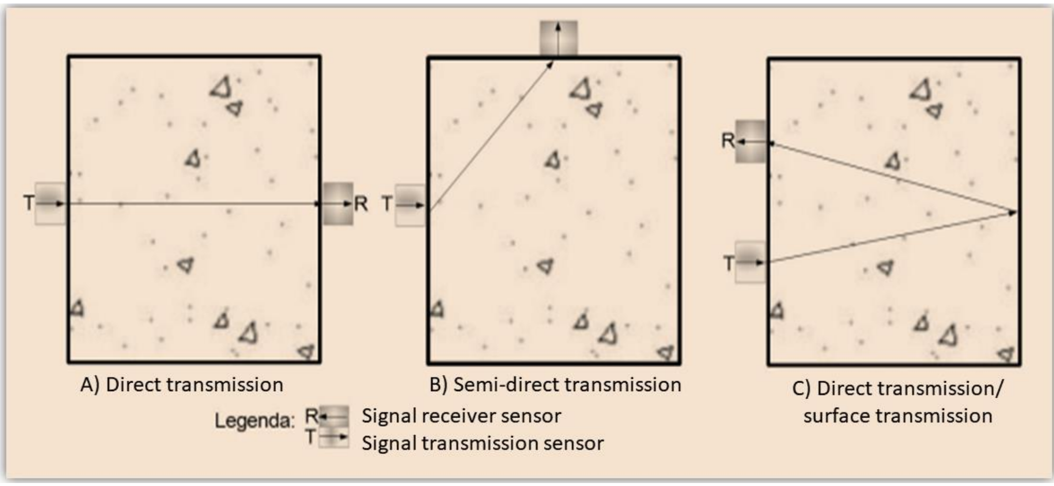
Figure 2. The measurement system, software, and transducers.



2.4 Measurements methods

The ultrasonic longitudinal propagation speed detection tests are performed using the through transmission method (seen in **Figure 3**, A), where the propagation time of the ultrasonic wave received by the transducer assists in calculating the time it takes to travel between the sides of the block.

Figure 3. Ultrasound transmission methods through specimens.



Source: Adapted from NBR 8802, 2021.

2.5 Environmental conditions

Tests were performed in a room with a temperature ranging from 23 °C to 25 °C and a humidity of approx. 50% to 75%. All measurements were performed on the same day for each specimen studied.

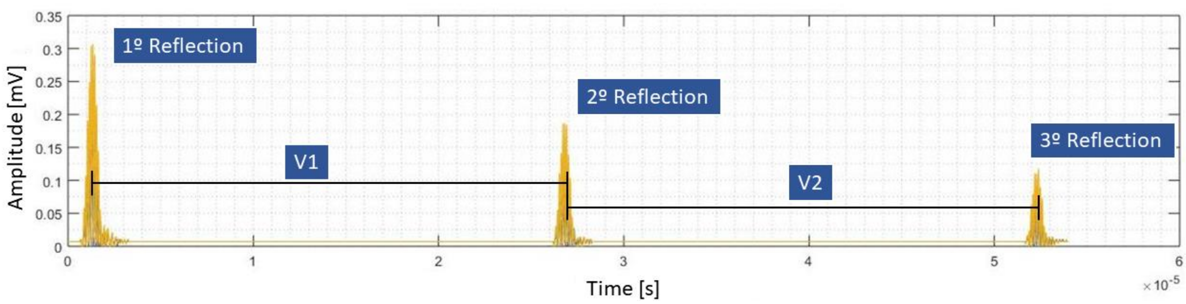
2.6 Amplitude and velocities assessment

From the time of flight (*s*), the time transmission velocity inside the specimens has been calculated by (1). The amplitudes were taken directly from the Labview™ automatically acquired on the oscilloscope's screen.

$$V = \frac{\Delta S}{\Delta t} \quad (1)$$

Where:
V is the sound propagation speed in $m{\cdot}s^{-1}$
ΔS is the thickness of the carbon steel block in meters.
Δt is the average time the ultrasound travels inside the specimen in seconds.

Figure 4. Wave pic reflections and ultrasonic pulse velocity assessment.



3 Results and discussion

Figure 5 presents the results of amplitude versus contact forces imposed on the transducers for one of the rounds performed. It is possible to notice the energy growth for each of the three amplitudes for the reflections occurring on the walls of the block. **Figure 6** shows the behaviour of the longitudinal velocity also with the increase in the contact force. This graph showed no tendency to change with the increase in contact force, indicating that this property was not affected by the force variation.

Figure 5. Amplitude and applied contact force.

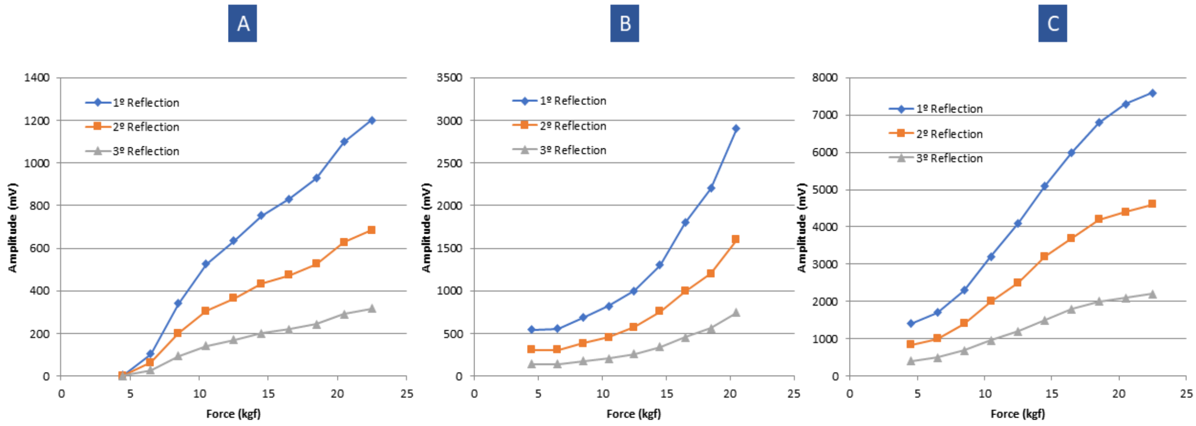
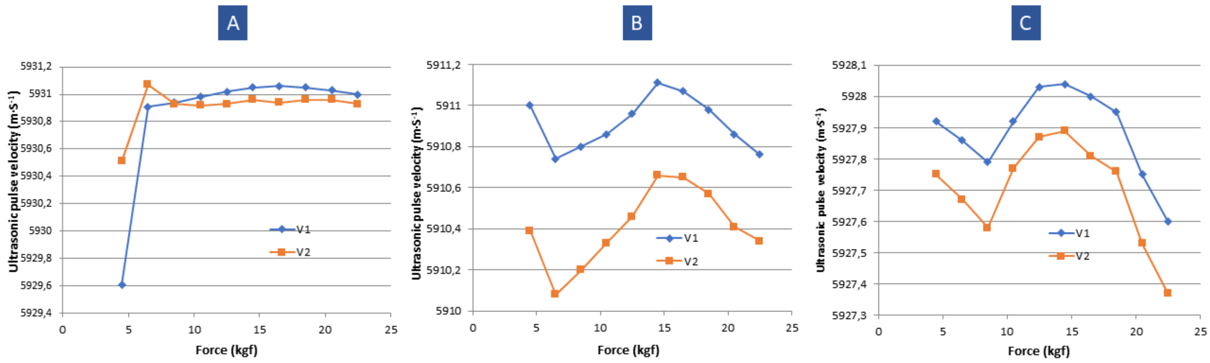


Figure 6. Longitudinal ultrasonic velocity and applied contact force.



From the initial results of ultrasonic velocity in the analyzed blocks, it was impossible to observe growth or decrease trend (see **Figure 6**). However, what will be worth investigating in future work is whether there is a contact force in which the measurement uncertainty obtained is minimal.

Regarding the amplitude of the signals, it was observed that the growth behavior of the three amplitudes analyzed, for each of the peaks of the identified reflections has the same behavior. However, it is observed that the variation rate was different for the three analyzed blocks. That is possibly due to how the coupling conditions promoted by the increased applied external force varied in each respect.

4 Conclusions and future works

This work conducted preliminary research to evaluate the contact force imposed on transducers in 03 carbon steel samples. Based on the experiments and discussions, the initial conclusions indicated that the increase in the contact force favors the coupling between the transducer and the sample. This effect allows more energy to be made available to the system. No significant differences were identified regarding longitudinal velocity, which intuitively seemed to be expected. Although the coupling conditions are changed, the acoustic path can be considered identical.

The results found for these carbon steel samples are significant. They will serve to better define the measurement protocol for more complex samples of measurement, and that will possibly occur more alterations. Because these materials have greater surface roughness, the changes are expected to differ from measurements in metals.

In future work, these quantities will be measured together with their respective uncertainties to verify if there is a force range that provides results with less uncertainty. In addition, other effects that may interfere with ultrasonic measurement can be evaluated, such as alignment between transducers, thickness, type of medium, and the impact of roughness on the measurement surface.

As a proposal for future work, new materials such as dicotyledonous wood, concrete and magmatic rock will be analyzed. Additionally, it is believed that further research evaluating the contact force and coupling conditions of transducers may be relevant for research in humans:

1- Establishment of a contact force that is more comfortable for measurements in contact with humans; and

2- Contribute to verifying the repeatability of measurements by controlling the energy available to the system by defining the contact force and, respectively, the coupling conditions.

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