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Proficiency test on thickness measurement using ultrasound: A metrological aid to improve safety in transportation of dangerous products

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ABSTRACT

Introduction: Safely transporting dangerous products such as fuels and other chemicals depends mostly on the integrity of the tanks and vessels in which they are stored. Regular vehicular inspection using non-destructive testing is an important coadjutant to assure the quality and reliability of transportation vessels: for instance, thickness measurement using ultrasound equipment. Typically, vehicular inspections are done by accredited inspection bodies. One way to attest to the conformity of accredited inspection bodies is a proficiency test. This paper discloses a proficiency test in which accredited inspection bodies took part in performing ultrasound thickness measurement in tanker trucks and vessels used to transport dangerous products.

Method: A total of 59 participants participated in the proficiency test. An artefact was developed for the proficiency test, consisting of metal-walled hollow cubes whose thickness ranged from 2 to 12 mm. To be approved, the participants were required to yield measurement results statistically equivalent to the reference value for all 6 walls of the cube assigned to it, partially approved for an equivalent measurement for 2 to 5 walls and disapproved with one or no equivalent results. The statistics used involved the Z-score ($p = 0.95$).

Results: Five participants failed to provide a result during the proficiency test (9%), 16 were approved (27%), 35 were partially approved (59%) and only 3 were disapproved (5%).

Conclusions: The proficiency test disclosed that measurement system calibration plays an important role among the successful accredited inspection bodies. Technical training on metrological issues, leading to professional and technical certification, would also improve the general performance for thickness measurement using ultrasound.

Practical applications: Safety in transporting dangerous products depends on the capability to perform a good technical evaluation of the integrity of vessels and tanks, which can be evaluated with the aid of a metrological tool, called a proficiency test.

1. Introduction

Road-based transportation of dangerous products such as fuel and chemicals is of great importance in many industrial zones worldwide [1,2]. Both liquid and gas products are typically held in tanks transported by trucks or carts [3]. Tanker trucks are commonly used, as well. Regardless of the recipient, many countries have specific regulations regarding safety assurances or flaw prevention [4–6]. The risks to the environment are of concern, and authorities demand stringent technical inspections [7]. In the case of Brazil, for example, regulations require a mandatory inspection of the tanks used to transport dangerous products on regular roadways [8].

Among the mandatory tests and verification procedures is measuring tank wall thickness and integrity by ultrasound [9], a powerful tool used in an assortment of measurement protocols including flaw detection and determining the thickness of solid materials [10]. Ultrasonic non-destructive testing (NDT) methods are standardized by ISO [11], including the characterization and verification of measuring equipment [12]. Special attention shall be paid to the probe's characterization, without which unexpected and undesired results might occur [13,14].

Typically, a non-destructive inspection is performed by an accredited inspection body (AIB) as defined in [15]. Among the procedures to attest to the reliability of an AIB are proficiency tests (PT) as technically detailed in [16]. Typically, a PT is obtained with a laboratory-based intercomparison [17,18]. In this context, a pilot laboratory establishes a reference value for the measurand under consideration, and a group of participants demonstrate their proficiency by the realization of that measurand on their own. The measurand could be a quantity to be produced from an artefact, a piece of equipment to be calibrated or

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even a certified reference material – whatever applies to the final purpose of the PT [16]. The benefits arising from participation in a PT include the following:

- The participating laboratory receives a regular and independent external assessment of the quality of its results for tests and calibration.
- The laboratory may compare its performance with those of other similar laboratories.
- The obtained data could be used as an input for the implementation of preventive actions to improve laboratory procedures.

The goal of the present work was to evaluate the capability of Brazilian AIBs after their participation in a PT regarding ultrasonic thickness measurement of tanker truck vessels used to transport dangerous liquids. Eligible AIBs were those inspecting road vehicles for transportation of dangerous products. In Brazil, about 130 AIBs are dedicated to performing this kind of measurement, meaning that about 45% took part in the PT. The scope of AIB accreditation encompasses the tank's wall thickness in the range of 3–15.8 mm. The reference value for the PT was determined by the Laboratory of Ultrasound (Labus) at the Brazilian National Metrology Institute (Inmetro).

Despite the technical NDT nature of this work, the main background and motivation was to disclose metrological support for safe transportation of dangerous products on roadways.

2. Materials and methods

2.1. The measurand and the artefact

The PT was developed to assess the ability of an AIB to measure thickness using ultrasound according to a previously defined protocol. Accordingly, the measurand was thickness, and the protocol included a standardized ultrasound method [11].

The measurand was materialized in artefacts consisting of 10 metallic-walled cubes. The thicknesses of their walls were pseudo-randomly distributed so that all cubes had dissimilar sets of wall thicknesses. The cubes were hollow, meaning that inside the walls was nothing but air. Fig. 1 shows one cube positioned on the measuring system. All cubes were constructed using 6 square plates made of steel with a length of 100 mm, and their edges were joined by welding. The measurement protocol is presented in Section 2.2. Cubes were chosen as artefacts because it would not be possible to measure their wall thicknesses by any direct method such as using a vernier calliper.

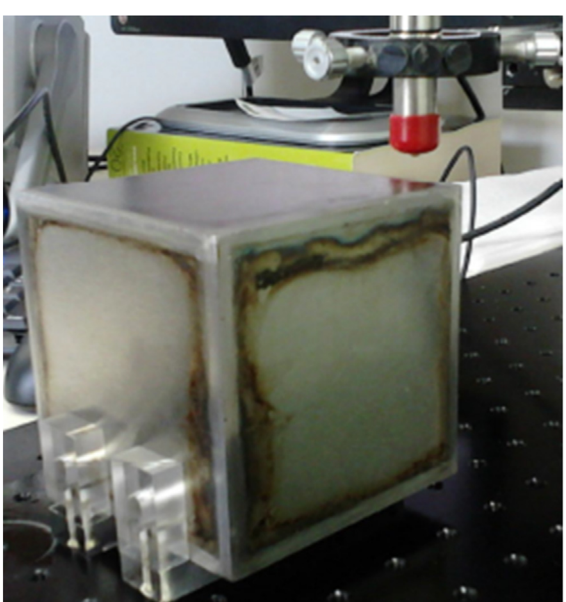

Fig. 1. Metallic cube, an artefact used as reference standard for the PT.

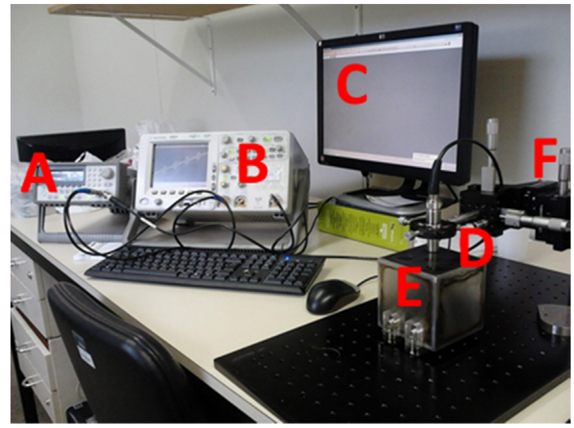

Fig. 2. Ultrasonic thickness measurement system. A → function generator; B → oscilloscope; C → computer; D → ultrasonic transducer; E → metallic cube; and F → transducer positioning system.

2.2. Determination of reference thickness values

The thickness measurement was done using the ultrasound pulse-echo method. The measurement system comprised a 100 MHz digital oscilloscope model DSO6032A (Agilent Technologies Inc., USA), an 80 MHz arbitrary waveform generator model 33250A (Agilent Technologies Inc., USA) and 5 MHz longitudinal wave transducer model V309 (Olympus Corporation, USA). Each piece of equipment was calibrated prior to the measurement. Fig. 2 shows the positioning system; placement of a cube facilitated measuring the thickness of its upper surface.

The transducer contained a piezoelectric element, excited by a short electrical impulse to generate a burst of ultrasonic waves. The transducer operated in a nominal frequency of 5 MHz and had a nominal diameter of 12.7 mm. The sound waves were coupled into the test material, travelling through it until they reflected from a back wall or another boundary or discontinuity. The reflections then travelled back to the transducer, which converted the sound energy back into electrical energy. The incoming signal was digitized with the aid of the scope and stored in a computer for postprocessing and calculations. The software was custom-made to process the signal and calculate the final quantity of interest, that is, the wall thickness using Eq. (1):

$$e = V\frac{t}{2}[m] \quad (1)$$

In which e is the sample thickness, V is the ultrasound propagation velocity in the testing material and t is measured round-trip transit time.

The time interval t considered is the average period elapsed between the first and the second echoes, and the second and the third echoes. This procedure eliminates the transit time through the coupling layer. In Fig. 3, the software's front panel is disclosed, and 3 small squares serve to mark the higher peak of the referred echoes. Those squares define the exact instant used to compute the round-trip time interval t, each of them related to one of the first 3 echoes. This point corresponds to the maximum peak of the reflecting signals. The homemade software automatically assesses the maximum peaks.

It is important to mention that the software was not distributed to any participant, as the purpose of the proficiency test was to evaluate the laboratory capability for providing good measurement results regarding thickness of carbon steel plates. Participants were intended to use their own method, equipment, and technical staff to perform the