DEVELOPMENT OF AN AUTOMATIC INSPECTION EQUIPMENT BASED ON THE TOFD TECHNIQUE.

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Abstract. *Non-destructive testing (NDT) is a powerful tool employed to asses the integrity of parts, equipments and structures. NDT techniques are widely used for discontinuities detection and measurement. Each method has its advantages and drawbacks and the choice of the adequate NDT method relays on the desired application.*

Although the radiographic test is broadly applied for welded joints inspection, the ultrasound technique (UT) is replacing it for many applications. Among all of the UTs, the time of flight diffraction (TOFD) technique is becoming more and more attractive. Besides getting over the problems for the radiographic inspection in relation to detection and measurement of defects perpendicular to the surface of the sample, the TOFD technique allows one to perform automatic inspection and the acquisition of permanent inspection records. It is possible to perform faster inspections with high reliability and low false identification rates.

The aim of this work was to develop an automatic inspection equipment based on the TOFD technique. This equipment is able to detect and measure defects in welded joints, metal sheets, pipes and other kinds of metallic structures so that the user influence on the data acquisition results is minimized and the test reliability is strongly increased. Its detection efficiency was determined based on the results acquired after inspections performed on test pieces in which well controlled defects were introduced.

Keywords: NDT, Ultrasound, TOFD, Automation, Automatic Equipaments.

1. Introduction

Non-destructive tests (NDT) are a powerful tool to warrant parts, equipments and structures integrity and so they are broadly used for detection and dimensioning of discontinuities in materials. There are many types of NDTs: penetrating fluids, magnetic particles, ultrasound, eddy currents, etc. (ASM Handbook, 1994, ASNT Handbook, 1991, ASNT Handbook, 1996). Each of them has its advantages and drawbacks depending on the material to be inspected, kind of discontinuity, material environment, etc. Thus, the choice of the most adequate method relays on the desired application.

Although radiography (RT) is widely employed to detect and sizing up discontinuities in welded joints, it requires special safety procedures, time to develop the radiographic frame and its response is all about the discontinuity length which is not enough to assess risk caused by the defect. Then, ultrasound (UT) is becoming the best choice to replace RT because there is no harm for the operator and discontinuities can be well dimensioned.

The arise of the time of flight diffraction technique (TOFD) (Silk, 1979, Silk, 1987) was a great progress for UT. TOFD has become more and more used because faster inspections can be performed with high reliability on the dimensioning and low false identification rates (Raad and Dijkstra, 1997, Verkooijen, 1995, Raad and Dijkstra, 1998). The ultrasound beam incides obliquely on the surface to be inspected so that RT drawbacks to detect and dimension discontinuities perpendicular to the surface part are overcome (Raad and Dijkstra, 1997, Verkooijen, 1995, Raad and Dijkstra, 1998). The automatic displacement of transducers combined with signal digitalization makes it possible to perform automatic inspections with permanent records.

The present work was aimed to build an automatic inspection equipment based on TOFD. It is capable of detecting and dimensioning defects in welded joints, pipes and several other metallic structures. The expectation is to reduce operator influence and increase test reliability. The efficiency of the equipment was evaluated based on inspections on test pieces with well controlled defects.

2. TOFD

To dimension defects by TOFD, the position of the signals generated by their extremities, i.e., the time difference between them is recorded. Thus, TOFD is weakely affected by differences in signal amplitude. The traditional setup for TOFD is one emitting transducer and one receiving both aligned to the weld bead in order to cover the interest region (Fig. 1) (British Standard BS7706, 1993).

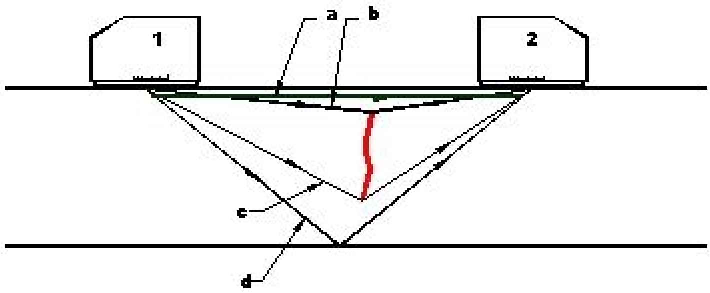

Figure 1 – Setup for TOFD: (1) Pulser, (2) Receiver, (a) Lateral wave, Diffracted wave from the upper (b) and lower (c) extremities of the defect and (d) Backwall echo.

A-scan mode (Fig. 2) is the most typical form of the ultrasound signal, and it consists of the signal itself, amplitude versus time, which is displayed on the ultrasound equipment screen. The first pulse to achieve the receiver corresponds to the lateral wave that propagates under the upper surface of the test piece. If there is no discontinuity, the second pulse will be the backwall echo. Any other signals generated from the discontinuities will be recorded between the surface wave and the backwall echo because they respectively correspond to the shortest and longest possible trajectories between the pulser and the receiver. So, the signal from the upper extremity of the discontinuity arrives before that from the lower one. The discontinuity height can be calculated from the time of flight difference between these signals (British Standard BS7706, 1993). The lateral wave and backwall wave are generally used as reference to measure the time of diffraction of the other waves.

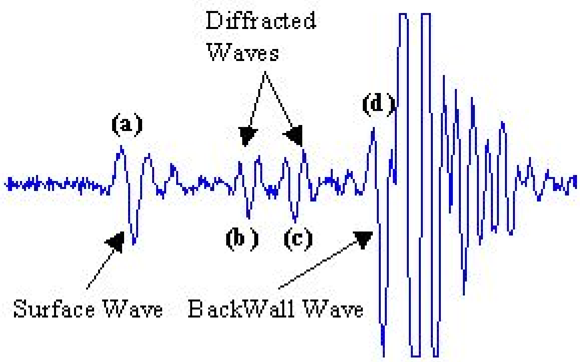

Figure 2 – Typical A-scan (amplitude *versus* time) obtained by TOFD.

3. Experimental Setup

The automatic inspection equipment by TOFD developed during this work is composed by: a software to control the system via a personal computer (PC) connected to the ultrasound equipment and to the mechanical system (scanner) via the electronic system (driver). The equipment setup is presented in Fig. 3.

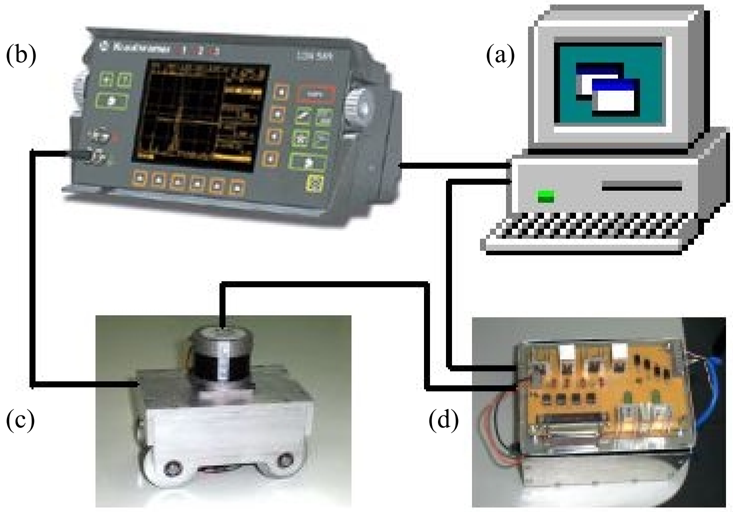

Figure 3 – Equipment setup used to non-destructive testing: (a) the control system (personal computer) is connected to the (b) ultrasound equipment and to the (c) mechanical system (scanner) via the (d) electronic system (driver).

3.1. Mechanical System

The scanner (Fig. 4) carries the ultrasonic transducers and produces the best possible coupling among them and the region to be inspected. Conveniently, the scanner was planned with built-in magnetic wheels to make it possible to inspect ferromagnetic structures in all possible locations, upside down included.

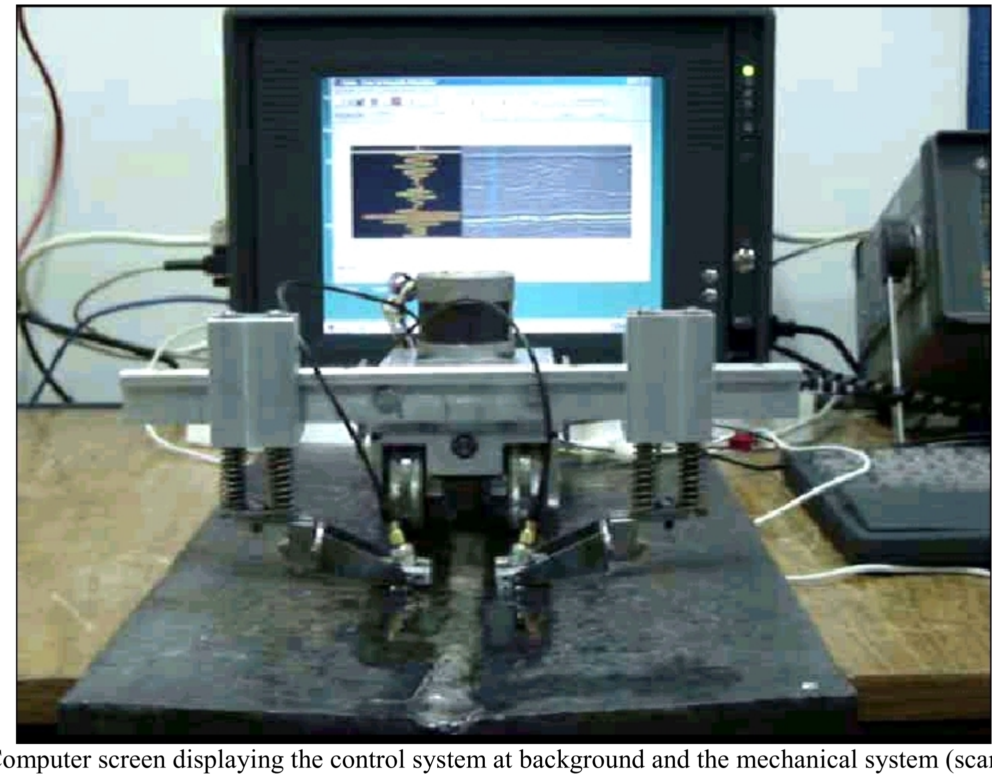

Figure 4 – Computer screen displaying the control system at background and the mechanical system (scanner) during a testing of a weld bead.

3.2. Electronic System

The PC is connected to the scanner by the driver. Many different electronic circuit designs were proposed and evaluated until the best solution was applied: a driver with programmable microcontrollers. This increases system efficiency and makes it independent of the operational system. The connection between the PC and the driver is made by the parallel port.

3.3. Control System

The control software manages the ultrasound on-line, real time data acquisition with scanner positioning. It was written in Borland C++ builder 6 and allows: (a) choice of communication ports with the driver and (b) with the ultrasound equipment, which sends signals to the computer, besides (c) the choice of data transmission rate. With all these parameters input, the user can displace transducers to setup initial inspection position or perform the inspection itself.

During inspection, several ultrasonic signals named A-scan are acquired and employed to build an image named D-scan. The D-scan is the image of the longitudinal cut of the inspected region produced by the successive records of the several A-scans obtained during the transducers displacement perpendicular to the ultrasonic beam. The D-scan, presents amplitude values in a gray scale so that the defects can be viewed.

These A-scans and D-scans are ways for the control software to present results. When a new inspection is performed, results can be saved as a DAT file or a BMP image. The result saved from a performed inspection can be reloaded at any moment to be analyzed. Calibration and sizing tools were also added to control system and permits a simple and precise sizing of the defects detected during inspection.

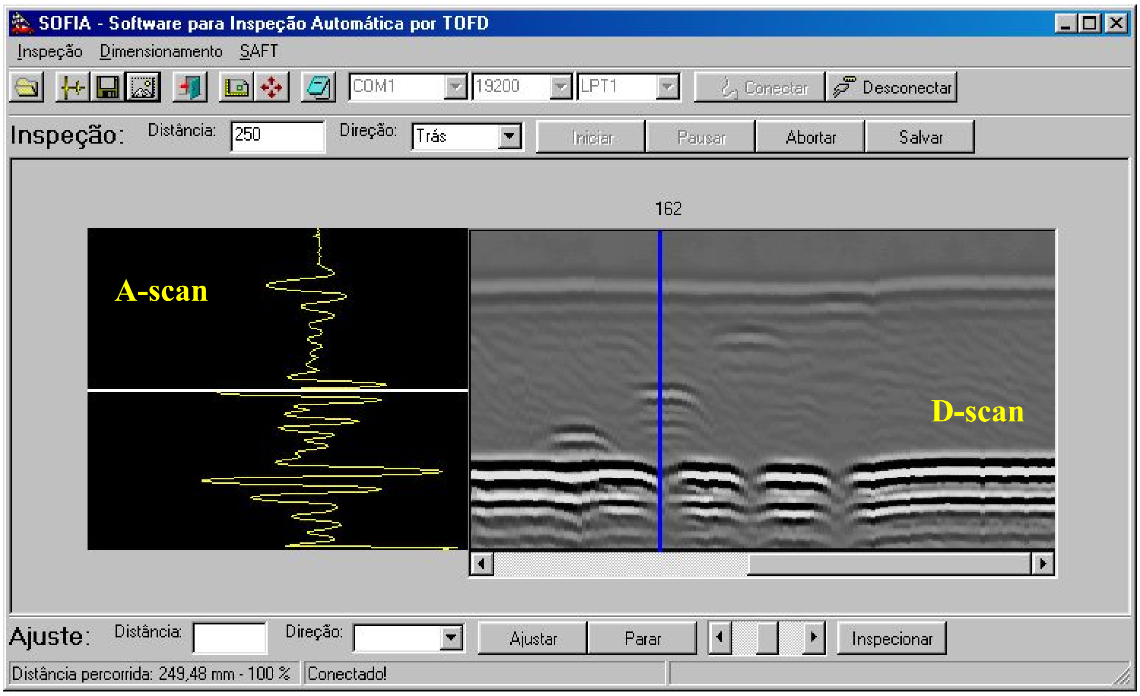

Figure 5 – Control system interface showing the result of an inspection.

With click of mouse, an A-scan can be selected from the D-scan. The control software marks a blue line on the D-scan and the correspondent A-scan is present to the left on the screen (Fig. 5).

3.4. Test pieces

Different test pieces were machined from a 18 mm thick and 600 mm long AISI 1020 steel plate. Different defects were inserted by electric spark erosion. This machining procedure warranties the dimensional precision of the inserted defects (Fig. 6). As the real dimension of each defect is well controlled, the efficiency and reliability of the equipment can be better evaluated.

This test piece was specially planned to evaluate the reliability and efficiency of the calibration and sizing tools. Four 10 mm long grooves were inserted on the left side, 10 mm equally spaced but with different depths. On the right side, 10 holes were drilled with 10 mm depth but with different spacements from each other. The greatest spacement was 12 mm, bigger than the theoretical spatial resolution of the transducers, and the shortest was 4 mm, shorter than the theoretical spatial resolution of the transducers. Then, this same test piece will be useful to evaluate the influence and efficiency of the use of SAFT (Synthetic Aperture Focusing Technique) as signals processing techniques to improve the resolution of the system in a next stage.

Another test piece was made with two 19.05 (3/4 inch) mm thick, 600 mm long AISI 1020 plates welded by girth weld via shielded arc metal welding (SMAW) procedure. The weld bead contained intentionally inserted weld defects such as: lack of fusion; loss of penetration, porosity, etc. Besides these two test pieces, other ones were obtained from industry as parts of welded piping.

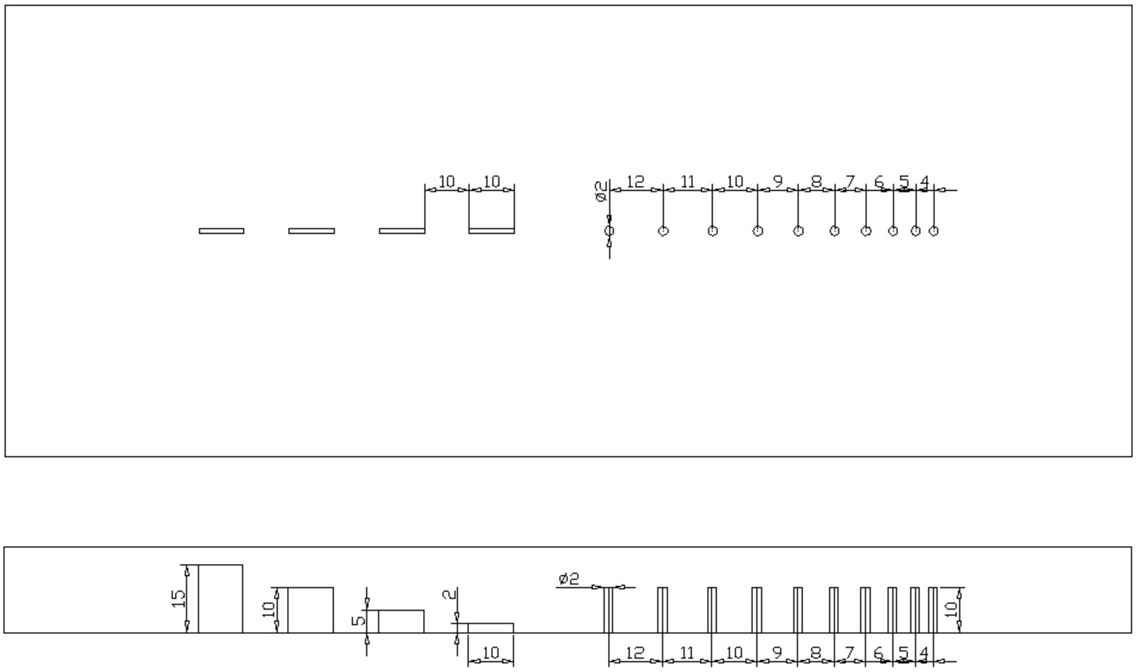

Figure 6: Upper and side views of the spark eroded test piece.

3.5. Inspections

The developed equipment was employed during inspections by TOFD in test pieces as described above. 5MHz MSW/QC/PC Krautkramer transducers for longitudinal waves with 6 mm in diameter were mounted on acrylic wedges at an incident angle of 60º. Couplants normally used for contact inspection include water, oils, glycerin, petroleum greases and various commercial pastelike substances. In this work, the couplant used was oil (SAE 40). A conventional USD15 - Krautkramer ultrasound equipment connected to a PC was used. The A-scans were acquired at each 1 mm during transducers displacement following the weld bead.

4. Results and Discussion

The two rolling surfaces of the spark eroded test piece were inspected in order to acquire signals from the surface on which the groove holes arise (A side) as well as from the other one (B side). Figs. 7 and 8 present the D-scan generated after each inspection as well the side view of the test piece on the respective position for comparison. Discontinuities inserted on the test piece and detected by inspection can be recognized.

It is possible to note the difficulty to detect defects nearer to the inspection surface from figs. 7 and 8. This is a TOFD drawback already observed by Silva (1999) and Silva (2000). It resides on the fact that a short time range Δt between two peaks is difficult to measure no matter the ultrasound equipment time resolution. It also possible that a defect near to the surface can be in the dead zone and in the near field. Lateral and diffracted waves can be also overlaped. For example, the defect nearer to the surface (2 mm depth) was not detected on the B side during inspection (*).

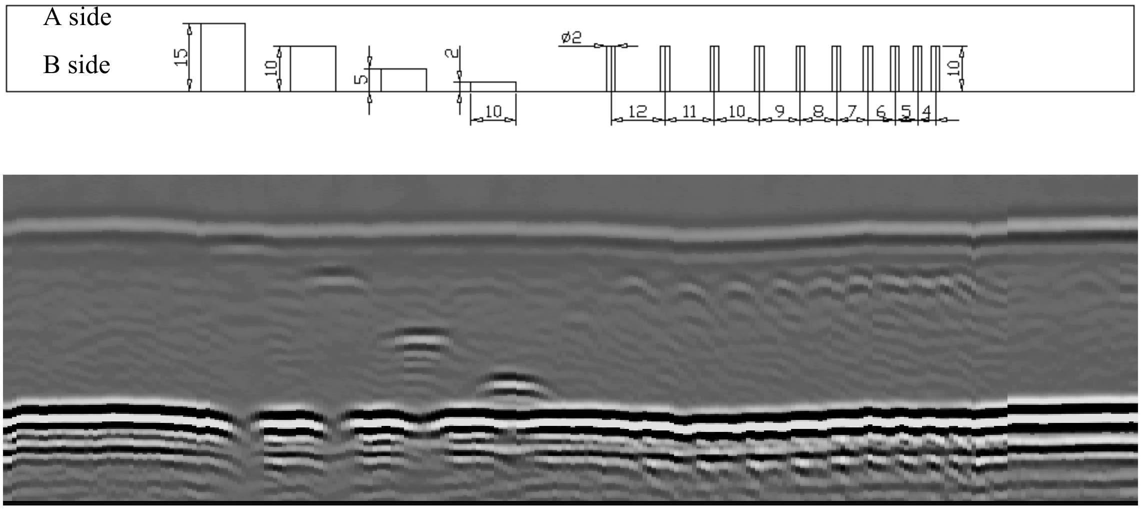

Figure 7: Side view of the spark eroded test piece compared to the D-scan generated after inspection on the A side.

Table 1: Comparison between real and measured dimensions after inspection made on the A side.

Defect (grooves)	Real depth [mm]	Measured depth [mm]	Measured length [mm]
#1	3	4,08	13,86
#2	8	6,70	12,87
#3	13	13,21	13,86
#4	16	16,01	12,87

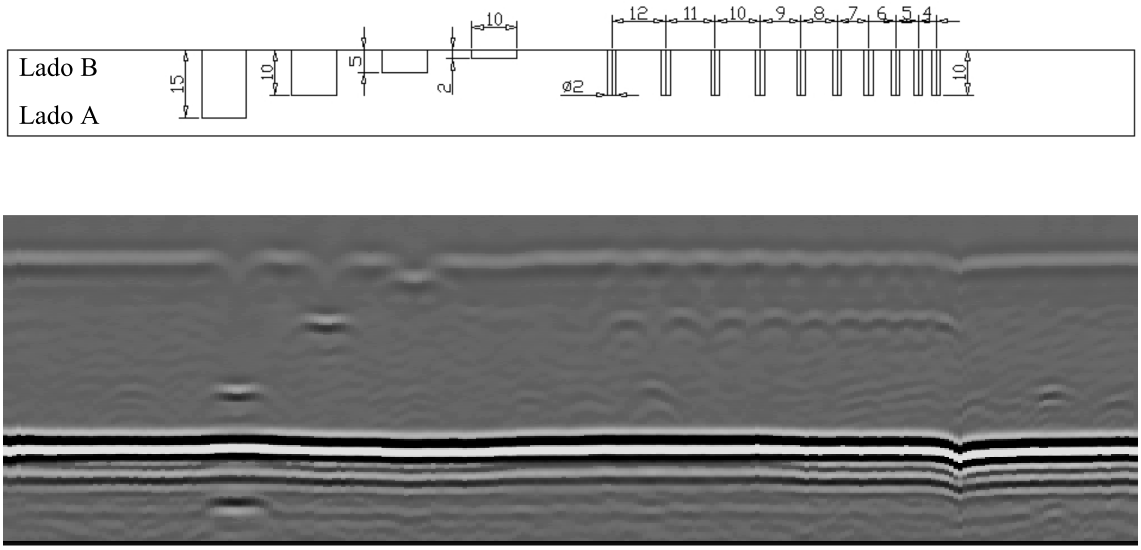

Figure 8 – Side view of the spark eroded test piece compared to the D-scan generated after inspection on the B side.

Table 2: Comparison between real and measured dimensions after inspection made on the B side.

Defect (grooves)	Real depth [mm]	Measured depth [mm]	Measured length [mm]
#1	15	14,72	8,91
#2	10	7,76	10,89
#3	5	3,01	8,91
#4	2	*	*

It can be easily seen on the D-scan (Figs. 7 and 8) that the two more spaced holes can be distinguished. It is also noted that it is not easy to resolve the next defects as they become less spaced. Then, this test piece will be also useful to evaluate the use of SAFT to improve the resolution of the system in a next stage.

Fig. 9 shows a comparison between the result obtained by RT and the TOFD equipment from the same region of the weld bead. The defect (lack of penetration) can be detected by both techniques.

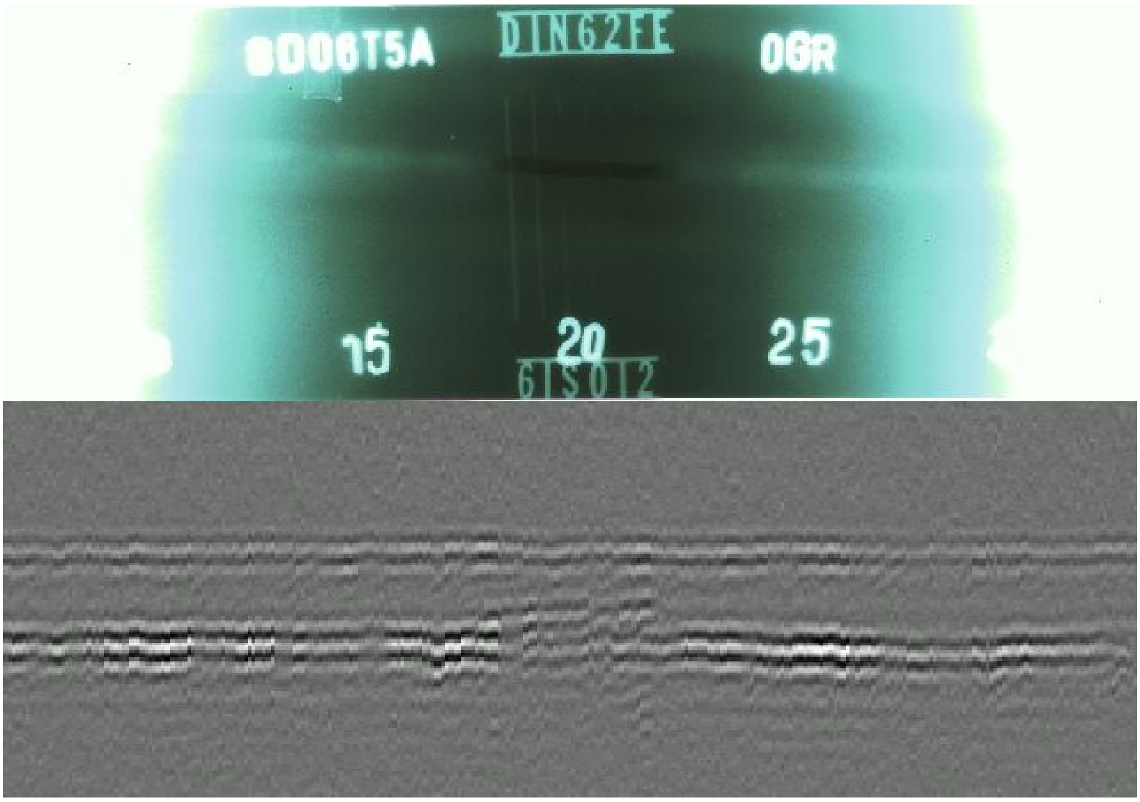

Figure 9 – RT image and D-scan from the same inspected region.

RT images are useful only to determine the defect length which is not enough to evaluate its significance whereas D-scans generated by TOFD make it possible to determine defects depth and length with reliability because the oblique incidence in the material bulk overcomes the difficulties of the RT in detecting and dimensioning defects perpendicular to the part surface.

5. Conclusions

An automatic TOFD inspection equipment was fully developed in CENDE - Center for Non-Destructive Tests of the Federal University of Ceará (UFC) during the present work. This system has successfully detected defects in weld beads performed with SMAW as well as test pieces with defects inserted by spark erosion defects with well controlled dimensions in order to determine the equipment efficiency and precision in dimensioning.

Such an equipment was capable of detecting and dimensioning defects in welded joints, plates, piping and several other metallic structures which makes it a good choice to replace RT, reduce operator influence and increase results reliability besides allowing permanent data record.

This equipment was a contribution to improve the infrastructure of laboratories in the Master of Science in Materials Science and Engineering Program of UFC

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8. Responsibility notice

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