TOFD inspection of V groove butt welds on the hull of a container ship with a magnetically adhering wall climbing robot.

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ABSTRACT

This paper presents the results of Time Of Flight Diffraction (TOFD) ultrasonic inspection of long welds on the hull of a container cargo ship. The TOFD probes are deployed by a low cost miniature climbing robot that adheres to the steel hull by using rare earth permanent magnets. 100% detection of defects sized larger than 0.6mm is obtained in V groove butt welds by a single pass scan. A scan and B scan results obtained by the inspection robot detect weld defects such as porosity, lack of root penetration and internal cracks.

1 INTRODUCTION

The hull of a typical container cargo ship, shown in Fig1, has external dimensions of typically 30m height, 30m width, 300m length and a perimeter area of some 200,000 m^2 (0.2 sq. km). The ship is constructed by welding prefabricated blocks in a dry dock. This constitutes many kilometre of welding length. Shipbuilding societies require that the welds are inspected before certification of sea worthiness can be given. These inspections are normally carried out using scaffolding/ladders etc. This is a danger to workers because of the heights involved, long hours spent in bad weather conditions and tedium. And also the length of time taken for human operators to perform all of this weld inspection has obvious implications for high labour costs and high incidence of fatigue-induced mistakes [1].

A magnetic wall climbing robot [1] designed by the authors to carry a 7 DOF serial link robot arm of mass 22kg to a maximum height of 30m on the outside surfaces of the hull of a container ship is shown in Fig2. The arm has been specially designed to perform remote inspection tasks. The climbing vehicle can move on surface curvatures presented by the hull of a ship and step over 40mm ridges that are formed by welding together steel plates of different thickness.

A number of other wall climbing vehicles have been developed for weld inspection [2,3,4,5] but they have some limitations in using the TOFD technique (e.g. a fixed skip distance, or suitable for pulse echo only etc.) and also they are very expensive and bulky. The low cost miniature magnetic vehicle reported here can perform 100% ultrasonic inspection of long welds to meet the demand of the ship building safety societies. It has options for selecting

variable skip distances during the weld inspections and can take measurement from different angles of the defect by steering the vehicle. Inspections from different angles of a defect increase the probability of detection (POD) and minimize the false call rate (FCR) [6].
The weld inspection has been performed by placing two probes (transmitter-receiver) on each side of the weld centre line. It gives a higher probability of detection than the conventional technique (a single shear wave angle probe from one side). A conventional technique sometimes cannot detect the defect in a Heat Affected Zone (HAZ) on the other side of the weld line. It requires two separate scans from both sides and hence takes a longer time. Also, this probe separation technique provides 100% detection of defects sized larger than 0.6mm by a single pass scan.

Although designed primarily for inspecting welds on the outer surface of the hull of a container ship, it could also be employed to test welds in ferrous components in hazardous environments such as chemical plants, oil storage tanks, etc [7].

Figure.1 Stern section of a hull of a container ship.

Figure 2. Magnetic climbing robot carrying a 7 DOF arm on a hull mock up.

2 THE MAGNETIC CLIMBING TOFD SYSTEM

The system consists of the following units: 1) Magnetic crawler 2) PC based ultrasonic TOFD system. The components of this system are described in the following section:

2.1 Magnetic crawler

The magnetic climbing vehicle reported here has been prototyped to perform ultrasonic TOFD inspection of vertical welds and the cross welds on the outside of a ship's hull. A miniature magnetic crawler is shown in Fig 3 and a section of vertical welds and the cross welds with magnetic crawler is shown in Fig 4. It consists of two DC servomotors and a differential gear box. One 15W DC motor is used for driving the vehicle forward or backward and another DC motor is used for steering the vehicle. Twelve pieces of 30x30x5 permanent rare earth magnets are glued to the underside of the vehicle to provide a clamping force of 110N to the vertical surface. The air gap between the magnetic vehicle and the steel surface is 6mm. The vehicle uses permanent magnets instead of electromagnets because permanent magnets have advantages for application in hazardous environments and they will not result in loss of adhesion in the event of power failure to the vehicle. The operator can remotely control the speed and direction of the vehicle via a 30m umbilical cable. Two probe holders have been attached to the vehicle to carry two ultrasonic emitter/receiver probes. The distance between the two probes can be changed. . Table 1 shows the specification of the crawler.

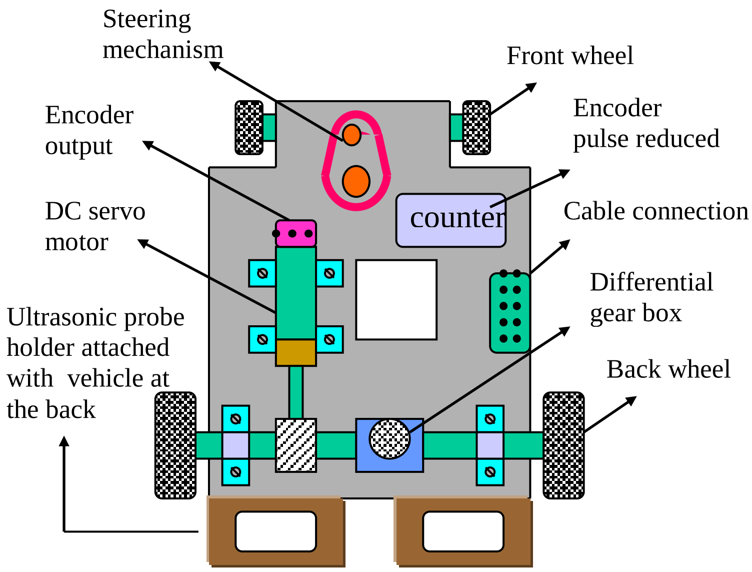

Figure 3. The magnetic crawler.

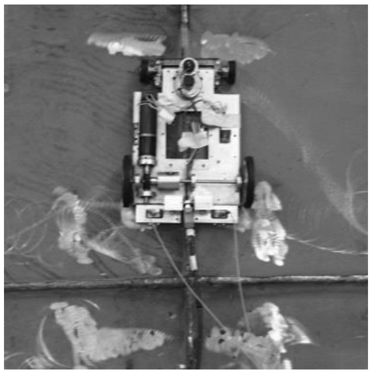

Figure 4: Cross Welds: 20 mm wide,11 mm proud of the surface with magnetic crawler.

Table 1. The magnetic crawler specifications.

Length x Width x Height	270mm x 220mm x 90mm
Weight including ultrasonic probe:	2.8kg
Maximum payload:	1.5 kg
Speed:	1 m per minute
Able to clear obstacles of height:	6 mm
Power supply:	12 VDC
Control of crawler:	The crawler can be controlled remotely either from a PC or a hand controller.
Umbilical:	The umbilical contains all the cables for the ultrasonic probes, drive motor and encoders.
Encoders:	Two encoders measure distance traversed and turning angles.

2.2 PC based ultrasonic TOFD system

The PC based ultrasonic system is shown in Fig 5. Two 10 MHz, 60^0 angle, ultrasonic longitudinal probes are used for inspection. The transmitter produces a 1 millisecond chirp every 200 milliseconds and the chirp contains 56 pulses. A transit time of 0.1 μsec for each pulse is produced by applying 200 volts.

Signals from the receiver are amplified by a broad-band amplifier (0.1-12 MHz), so to avoid aliasing in the digitisers, the signal is passed through 10MHz anti-aliasing filters. The filtered signal is digitised by an 8 bit waveform digitiser which operates at a sampling frequency of 100 MHz. This digitiser is triggered from the computer via a delay generator so that the start of the recorded signal from the receiver probe occurs just before the arrival of the lateral wave. The length of each recorded signal is chosen to cover a depth range from which adequate signals can be expected.

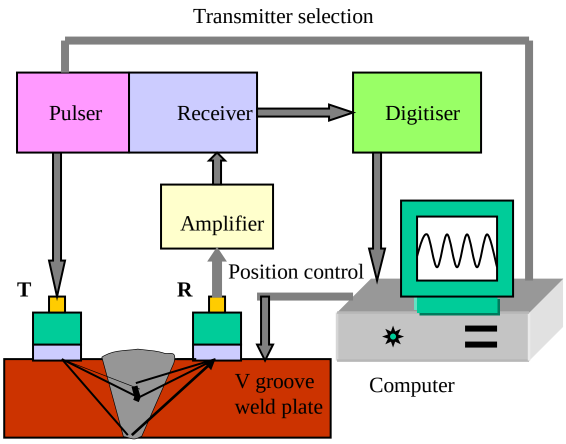

Figure 5: PC based TOFD system.

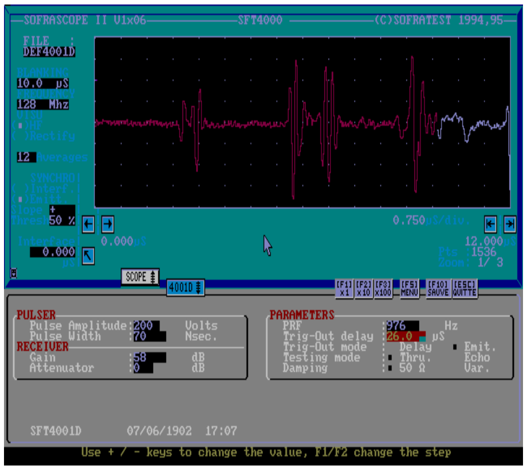

Figure 6: Ultrasonic TOFD scanning software menu.

Ultrasonic data from the pulser-receiver device is collected directly by a 64MHz A/D card plugged into the expansion bus of the PC. The sampling rate can be varied from 250 kHz to 32 MHz and the acquired data stored in memory at the rate of 4 Kb/channel. All features including the sample rate, trigger selection, threshold levels and interrupts are programmable. Other features that can be defined by the operator include multiple gates, pulse repetition rate, pulse width, gain and damping. Both A scan and B scan data can be displayed on the screen. A-scans are stored in a B scan line buffer and hold up to 512 rectified A-scan samples. Colours of the B scan image follow a standard linear scale in 1/16 steps. The SOFRA test software menu for the ultrasonic TOFD technique is shown in Fig 6.

2.3 Weld defect inspections

For testing purposes, a section of a hull has been engineered by the Odense Steel Shipyard and installed in the Centre’s laboratory. The welds are V groove butt welds. The vertical weld has dimensions of 190 cm long, 20mm wide, and stands 11mm proud of the surface. A range of known defects have been artificially inserted into the cross weld. A start and stop command was used to build up a B scan for the selective weld areas. Each B-scan amplitude level is represented by a colour. A colour palate is shown in Fig 9. The colour range of the palate is 0 to ±100 dB and each colour is separated by 12.5 dB. Ultrasonic parameter set up during the TOFD inspection is shown in Table2.

Table 2: Ultrasonic parameter set up.

Pulse Amplitude	200 volts	Damping	50 ohms
Pulse width	70 nsec	Blanking time	10 µsec
Gain	45-55 dB	Digitising sampling rate	100MHz
PRF	1kHz	Threshold	50%
Trig-out-delay	22 µsec	Testing mode	Through transmission

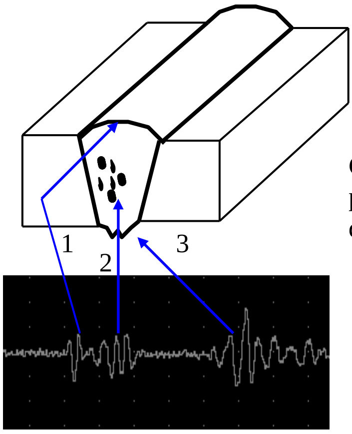

Figure 7: Porosity A-scan obtained from the V groove weld.

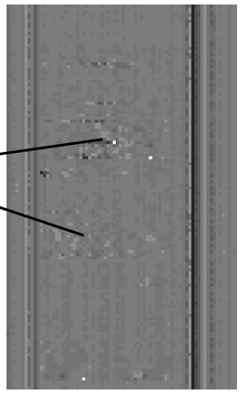

Figure 8: Porosity B scan image.

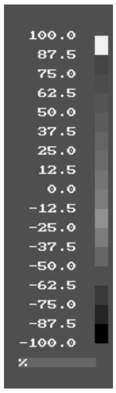

Figure 9: B-scan image color Platte.

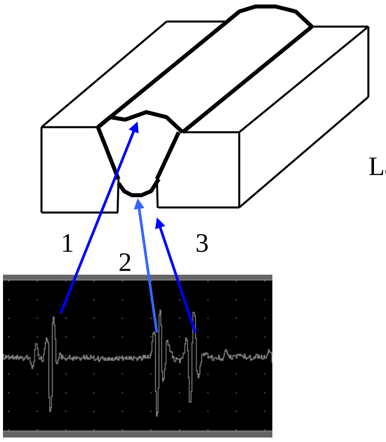

Figure 10: Incomplete root penetration weld defect A-scan obtained from the V groove weld.

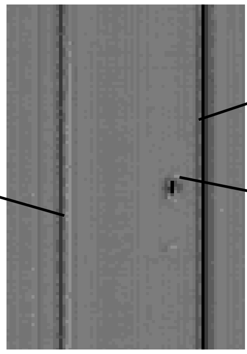

Figure 11:Incomplete root penetration weld defect B scan image.

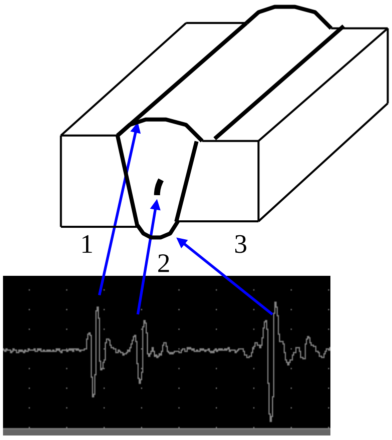

Figure 12: A scan obtained from an internal flaw of the V groove weld.

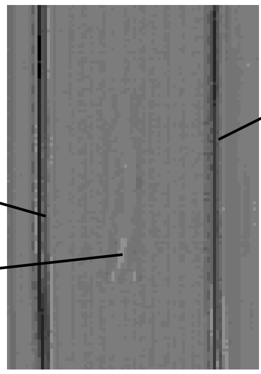

Figure 13: Internal crack B scan image.

1 - Lateral wave signals, **2** - Signal from the defects **3** - Back wall echo signals

Three different types of defects have been detected in the V groove butt weld by using the ultrasonic TOFD technique. The weld defects are: clustered porosity, incomplete root penetration and internal cracks.

2.3.1 Clustered porosity defects

The clustered porosity is most often caused by improper welding techniques, contamination, or an improper chemical balance between the filler and base metals. A scan result obtained from the clustered porosity is shown in Fig 7. The gain was set up as 51 dB. The typical TOFD pattern image is presented in the B scan. The scanning direction was perpendicular to the plane of the drawing. Indications of clustered porosity are displayed in the B scan between the lateral wave and back wall echo. It is shown in Fig 8.

2.3.2 Incomplete root penetration defect

Incomplete root penetration defects occur when the weld penetration of the joint is less than that needed to fuse through the plate or into the preceding weld. A picture of incomplete root penetration and corresponding A scan signal is shown in Fig10. The first signal in the A-scan is from the weld surface, the second signal is from the incomplete root penetration defect and the third signal is from the back wall echo. The gain was set to 45 dB. An indication of the incomplete root penetration defect obtained by the B-scan image is shown in Fig 11.

2.3.3 Internal cracks

Internal cracks develop in the weld as the weld pool shrinks and solidifies. Low melting materials are rejected toward the centre of the weld while freezing. Since these materials are the last to freeze, they separate, leaving cracks. An A-scan signal obtained from the internal crack is shown in Fig 12. The second signal indicates the defect from the internal crack. B-scan image for the internal crack is shown in Fig 13. The gain was set to 48 dB.

CONCLUSION

Tests show that three different types of weld defects (porosity, incomplete root penetration, and internal crack) can be detected in remote V groove butt welds by using the TOFD technique deployed by a very simple magnetically adhering robot that provides access to vertical and horizontal welds on the hull of large container cargo ships. The very small size and simplicity of the robot should enable it to be made completely autonomous with on-board power, embedded PC, Ultrasonic flaw detector and wireless Ethernet communications with a Client PC on the ground used for control and data acquisition.

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