AUTOMATED OFF-SHORE STUDLESS CHAIN INSPECTION SYSTEM

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Abstract: This work deals with the design and in-house operational results of a novel Automated Ultrasonic Inspection System (ASCIS) for studless chain links with diameter ranging from 111 to 185 mm, conceived and developed by INTERLAB Ingeniería Electrónica (IIE) for VICINAY Cadenas, a major industry devoted to manufacture of chains for both the shipbuilding industry and offshore exploration.
The system employs an arrangement of transmitting and receiving probes specifically designed to detect possible flaws in the weld area of each link, while providing the additional benefits of an automated inspection system.

Introduction: Chains used in mooring systems for offshore applications are subject to harsh mechanical and environmental conditions, which call for tight observance of strict quality standards[1], [2] during manufacturing to guarantee continued performance throughout their operational life. In studless chains, each link is made from a steel bar bent to join its ends through a Flash Butt Welding (FWB) process (electrical non addition welding system), which leads to a concentration of manufacturing flaws in the soldered area.

The main target of the project described herein was the development of an automatic system capable of detecting all possible flaws in the soldered area of chain links with diameters ranging from 111 to 185 mm, including those inner flaws which can not be reliably detected by an standard manual inspection. Additionally to this main objective, the designed system had to be capable of in-line link inspection, without hindering production even when ultrasonic inspection of 100% of the production is required [2].

The system to meet all these requirements has been designed around ULTRASEN®, a fully modular ultrasound system developed by IEEE for automatic and semiautomatic ultrasound inspection applications. It totally inspects the two sides of the welding zone of each link activating both acoustic and visual warnings when a flaw is detected. Additionally, graphical display, storage and hardcopy of inspection results are available to the operator.

In this paper, we present the design and in-house operational results (during two years of continuous operation) of the this inspection system, the first one in a series of eight units that will be installed in VICINAY for automatic ultrasonic inspection of a 100% of their production.

Results: According to the standard, manual inspection is performed with a single angle-beam probe, which the operator scans along the link side checking if the amplitude of any echo reflected from the solder area is larger than a pre-set threshold. This mode of operation is only valid for the detection of those imperfections within a plane parallel to the weld surface and located in the vicinity of the link surface (by corner reflection, see figure 1 centre), or those presenting a component normal to the ultrasonic beam (see figure 1 left). In order to enhance flaw detection, inspection is carried out from both sides of the solder plane.

However, due to the nature of the link manufacturing process, occasional imperfections in the weld area can be expected to be more or less parallel to the solder plane, but not always in a position to permit corner reflection, as shown in figure 1.

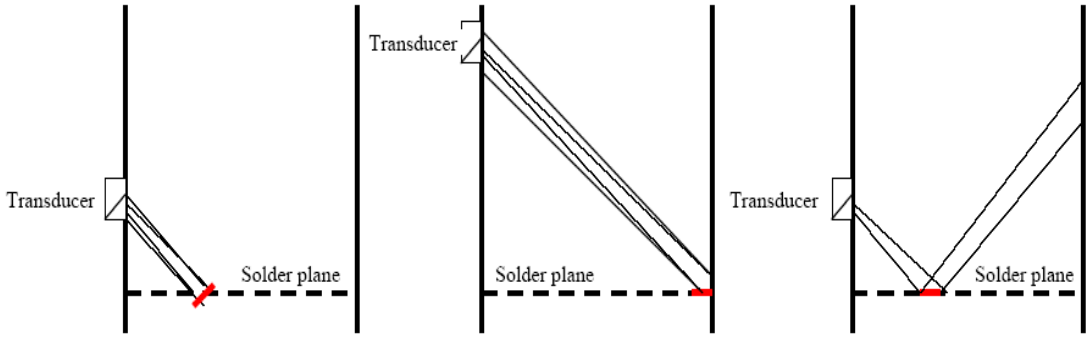


Figure 1. Flaw detection by single angle-beam transducer inspection. Inner imperfections normal to the probe beam (left) or edge imperfections parallel to the solder plane (centre) are detected, but inner imperfections parallel to the solder plane (right) are lost

In the automatic system, system, the problem discussed above is overcome by a four-transducer layout, where a pair of transducers inspects the upper side of the solder plane, and the other pair covers the lower side. In this configuration, all transducers operate in a conventional pulse-echo mode, waiting for echoes coming from imperfections within the weld area. Additionally, each pair of transducers operates in a transmit-receive mode, where one of them emits an ultrasonic pulse into the link, and the other receives possible echoes. This mode of operation allows for the detection of planar inner imperfections parallel to the solder plane, as shown in figure 2 for the upper pair of transducers (operation of the lower pair symmetrical).

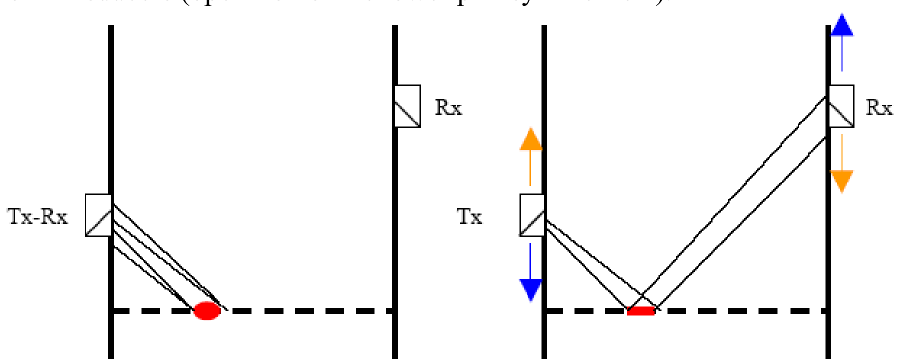


Figure 2. Proposed dual transducer inspection

During inspection, the transmitter and the receiver transducer movements must be synchronised (when one goes up, the other must go down by the same amount, see figure 2), so that the sum of their distances to the solder plane remains constant, according to:

$$h_{Tx} + h_{Rx} = D \times \tan\alpha \qquad (1)$$

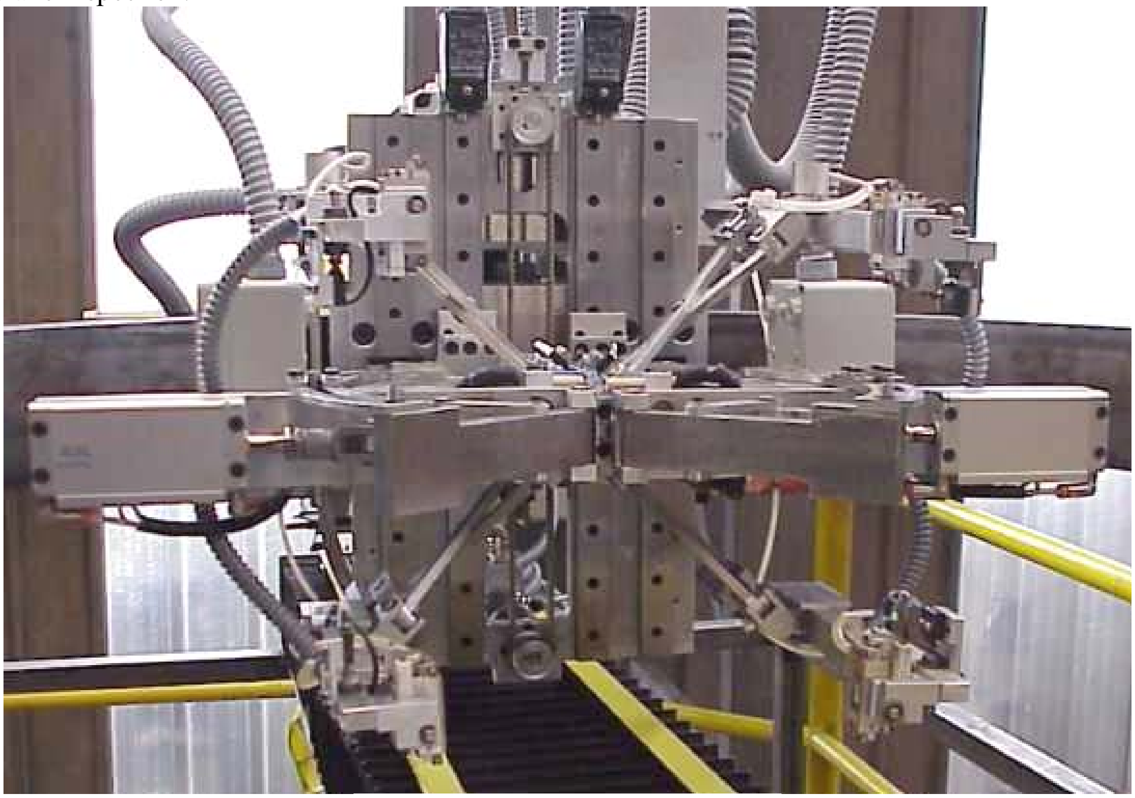
Where h_{Tx} and h_{Rx} are the respective heights of the transmitter and the receiver transducers over the solder plane, D is the link diameter, and α is the transducer beam angle.

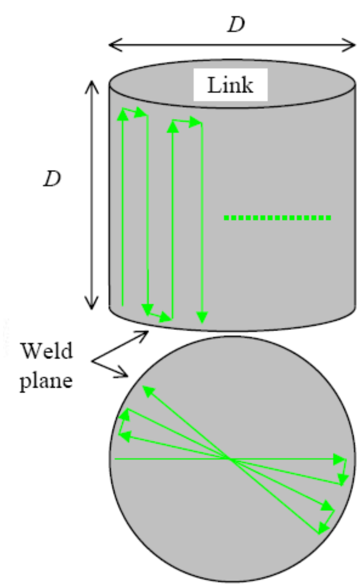
The chain links adjacent to the one being inspected set a practical limit that equals the link diameter, D, to the

maximum height that any probe can reach during inspection. The maximum theoretical height for either probe can be computed by making the other zero in equation (1), which yields:

$$h_{MAX} = D \times \tan\alpha \Rightarrow \alpha \leq 45° \qquad (2)$$

Since the standard [2] specifies angle-beam shear waves in the range from 45º to 70º, it is clear that 45º probes are the only option to avoid clearance problems. With these 45º angle-beam probes, the sum of the heights of the transmitter and the receiver transducers over the solder plane must remain equal to D (see eq. 1), which ranges from 111 mm to 185 mm. A specific double folding mechanism (see figure 3) has been designed for the transducer clamp, so that it self-adapts to each link diameter. Scanning the probes vertically along the chain side (thus scanning diameters of the weld plane), and rotating them around the vertical axis to scan the next diameter carry out the inspection. 0 to D vertical scan and ±90º angular scan, as shown in figure 3 achieves full weld plane inspection.





* Angle-beam probes

Figure 3. Probe self-adapting clamp (left) and scan pattern (right)

With the four-probe set-up described above, six effective inspection channels are available, where channels 1 and 4 provide optimum detection for imperfections forming reflectors at an angle of +45º with the weld plane, channels 2 and 5 provide optimum detection for imperfections forming reflectors at an angle of -45º with the weld plan, and channels 3 and 6 provide optimum detection of imperfections parallel to the weld plane (see figure 4).

Fault detection is achieved by the comparing the echo amplitudes for each channel with a threshold set by a calibration pattern. Prior to fault detection, the sets of data coming from redundant probes are merged to cancel out noise and enhance fault detection. It must be noted that this channel redundancy is achieved at no added cost in inspection time, since the movements of all four probes are simultaneous (vertical distance between probes P1 and P3 is always D, and the same applies to P2 and P4).

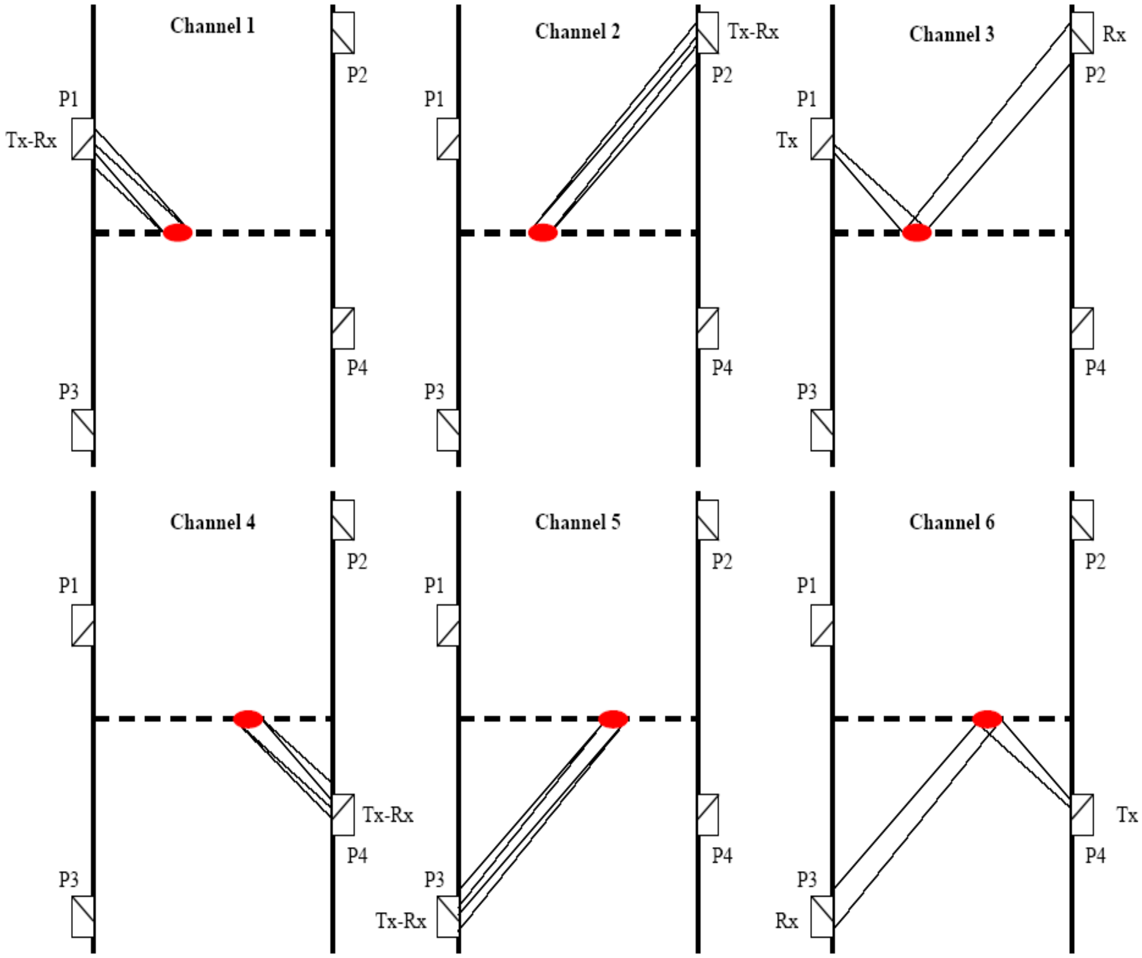


Figure 4. Six effective inspection channels are obtained with proposed four-probe set-up

In order to implement the inspection method described above, a specific system was designed to perform the basic functions of scanning the four probes along the link surface, while triggering, processing a storing the ultrasound echoes in precise synchronism with the position of the probes. All the tasks pertaining control of the electromechanical scanning system and real-time ultrasound data processing are carried out by an ULTRASEN® core, a fully modular real-time ultrasound signal processing system developed by INTERLAB for automatic and semiautomatic inspection applications.

In this particular application, the tasks required to ultrasound signal processing include triggering the probes in synchronism with the encoder signals and amplifying, filtering and digitising the received echoes. Once digitised, the signals are processed by a 2D digital filter, which can be programmed for maximum versatility. Finally the filtered signals are processed by a digital peak detector, which computes the co-ordinates (amplitude and time of flight) of the maximum echo value within a programmable time window which is recomputed according to probe positions in order to keep it centred upon the solder plane.

These co-ordinates are fed to the computer hosting the Man-Machine Interface (MMI). The MMI receives the pre-processed ultrasound data from the system hardware, and compares the echo amplitude received in each channel with a threshold value obtained from the calibration link, which is machined to provide samples of the maximum allowable fault sizes in the weld area. The inspection results are presented to the system operator, in the form of a synthetic C-Scan image displaying the composite echo amplitudes for each inspected link, plus a warning if the link is considered faulty.

Local databases store calibration results and dates, and the inspection results of each individual link inspected. These results include a record of the ultrasound echo amplitudes, so that the inspection of any inspected link can be recalled and re-evaluated whenever required.

Discussion: During normal system operation, the only manual task required of the operator is to position the self-adapting clamp on the link to be inspected (the whole chain runs vertically through different manufacturing processes, including quality control). The system automatically inspects the link weld area and displays the results (see figure 5), giving visual and acoustical warning whenever a defect is detected. The system is designed to limit inspection time to around 2 minutes per link, depending on link diameter.

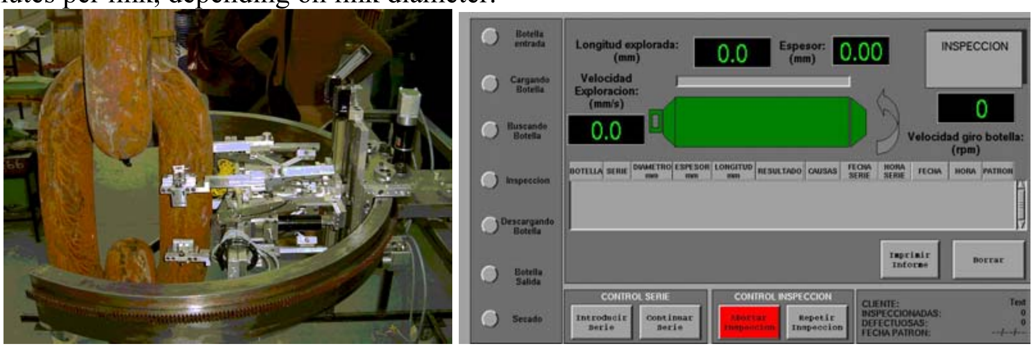


Figure 5. System in operation upon a link (left) and sample of inspection results (right)

Automatic calibration is identical to inspection, except for being a particular inspection of a reference block corresponding to the type of chain being currently manufactured. The system automatically identifies the fault pattern upon the reference block and adjusts its amplitude thresholds accordingly.

The reference block includes a total of five reference reflectors; two surface notches of size depending upon link diameter oriented 180º apart as specified in [2], and three inner flat bottom holes of a surface equivalent to that of the surface notches. One of the inner reflectors is in the centre of the solder plane, and the other two are set R/3 (where R is the link radius) away from the centre one. The reference block for 175-mm links and a sample of calibration results for this block showing the positions of the five reflectors are presented in figure 6.

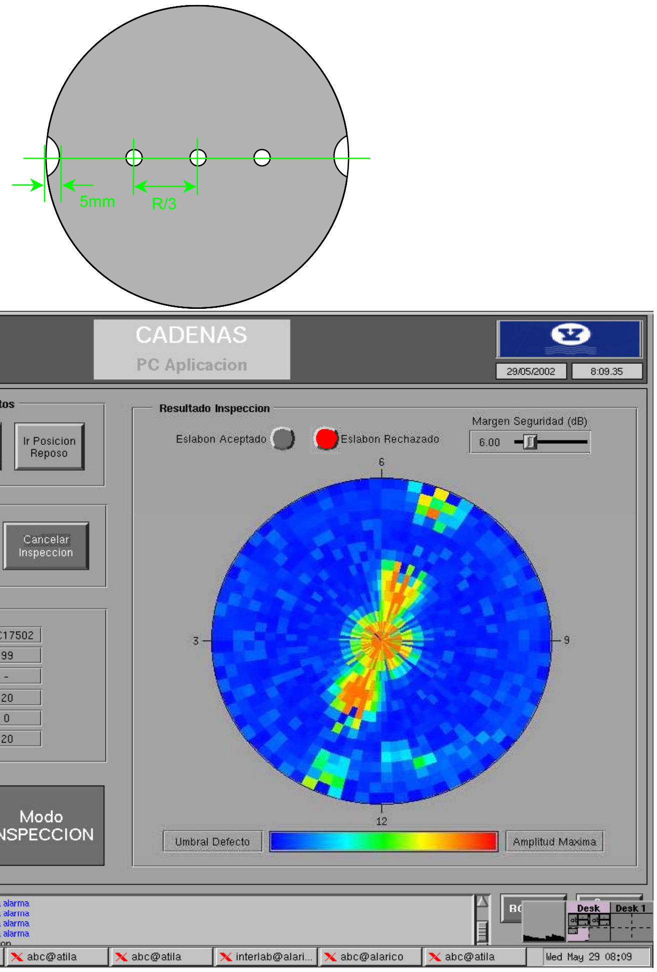


Figure 6. Cross-sectional view of reflectors in reference block and sample of inspection results

Conclusions: The system described herein has been operational in VICINAY-Cadenas for a period of two years undergoing the test of real in-house operation in a harsh industrial environment. During this period, the general validity of the method described was demonstrated.

However, the system did suffer from reliability problems in the self-adapting clamp that positions the probes along the link, which were overcome by a redesign of the arms linking the probes to the double folding mechanism.

During this two year test period, the following main advantages of the automatic test system became self-evident:

- Thorough inspection is achieved, thanks to the use of four probes, inner planar flaws in the solder area can be easily detected
- Automatic system calibration allows for repetitive, operator independent results.
- Inspection time (below two minutes per link) has no impact on overall plant productivity.
- Inspection results can be stored and recalled for each link, and hardcopy reports can be printed when necessary.

The system is undergoing a process of external certification by an independent company, after which seven more units will be installed to perform ultrasonic testing of a 100% of the production of VICINAY-Cadenas.

References:

[1] "Guide for Certification of Offshore Mooring Chain" American Bureau of Shipping 1999.
[2] "Certification of Offshore Mooring Chain" Det Norske Veritas 1995.
[3] "Standard Practice for Ultrasonic Angle-Beam Examination by the Contact Method"
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