DETECTION OF CORROSION
IN BOTTOM PLATES
OF GAS AND OIL TANKS
USING
GUIDED ULTRASONIC WAVES
AND
ELECTROMAGNETIC ULTRASONIC
(EMAT) TRANSDUCERS

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1. ABSTRACT

Guided ultrasonic waves are capable of detecting corrosion in the bottom plates of storage tanks. Couplant-free EMATS search units allow for a time-saving, accurate inspection without cleaning of the coupling surface. This ultrasonic technique has a large potential for providing faster and more economical inspections.

2. INTRODUCTION

Bottom plates of gas and oil storage tanks have to be inspected at fixed intervals to ensure sufficient wall thickness and the detection of corrosion (wastage and pitting). The most common technique applied for this task in the chemical and petrochemical industry is the conventional ultrasonic straight beam technique using the longitudinal wave mode, see Figure 1. This technique has three main disadvantages:

- The coupling (inner) surface must be carefully cleaned to ensure a sufficient transfer of sound into the material.
- Scanning must be performed at high density (small scanning grid) to assure the detection of small pitting.
- Large areas have to be inspected (typically some 100 m^2) resulting in high costs and elongated inspection times.

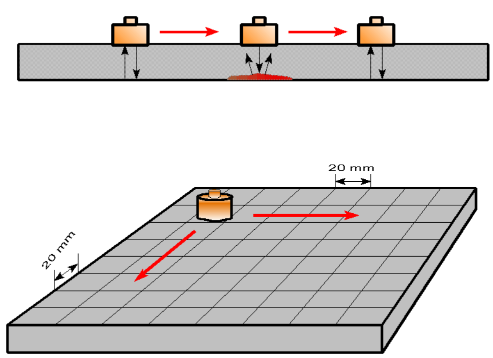


Figure 1: Raster Scanning

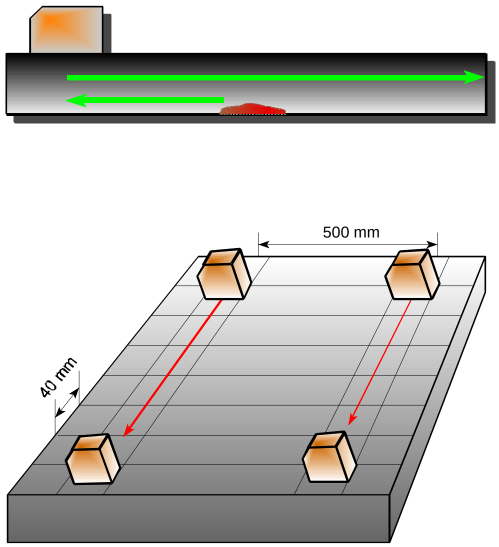
These disadvantages can be overcome by using a technique that inspects larger areas with sufficient sensitivity of detection and that works without any coupling medium.

The magnetic flux-technique [1] is working without a coupling medium; however, it requires a scanning of the whole surface area. Nevertheless the technique has been applied in the field with good success.

This report presents an ultrasonic technique using guided plate waves propagating over large distances. In addition, the use of **E**lectro-**M**agnetic **A**coustical **T**ransducers (EMAT) allows the technique to be applied on unprepared surfaces, if the scale on the coupling surface is no thicker than 1-2 mm.

3. GUIDED WAVE TECHNIQUE

The detection of corrosion can be performed using guided and horizontally polarized shear wave modes. As depicted in Figure 2, this wave mode is transmitted and received without the need of a coupling medium when using EMAT search units generating SH-waves.



Due to the guiding effect of the plate's inner and outer surface, SH-waves can propagate over distances of up to 1 m in plates having a thickness of several mm. Corroded areas on either plate surface are partially reflected due to local wall thickness variations. Instead of scanning the entire area with scanning offsets of 10 mm (or less) using straight beam search units, the guided wave technique requires only linear scanning of sections as long as 500 mm with a search unit offset of 20-30 mm, depending on the lateral sound field properties of the selected search unit. The economic benefits of EMAT are obvious.

Figure 2: Linear Scanning

When corrosion has been detected and localized by evaluating the pulse arrival time, a precise measurement of the wall thickness can be performed with an EMAT search unit. The physical principle of the reflection of SH-wave modes for local wall thickness variations is explained in Figure 3.

The "dispersion diagram" displays the sound velocity of the SH-waves as a function of the product of frequency ***f*** and plate thickness ***d***. The different curves represent the dependency of the velocity of different SH-wave modes as a function of

$$f/d\,.$$

These modes are classified by numbers (***n***= 0,1,2,3..) and differ in the variation of their particle displacement in the thickness axis. The wave mode displacement is always parallel to the surface.

Example: Transducer Period - λ = 8mm
Plate Thickness - d = 6mm

Operating Points: AS_1 483 kHz
SS_1 675 kHz

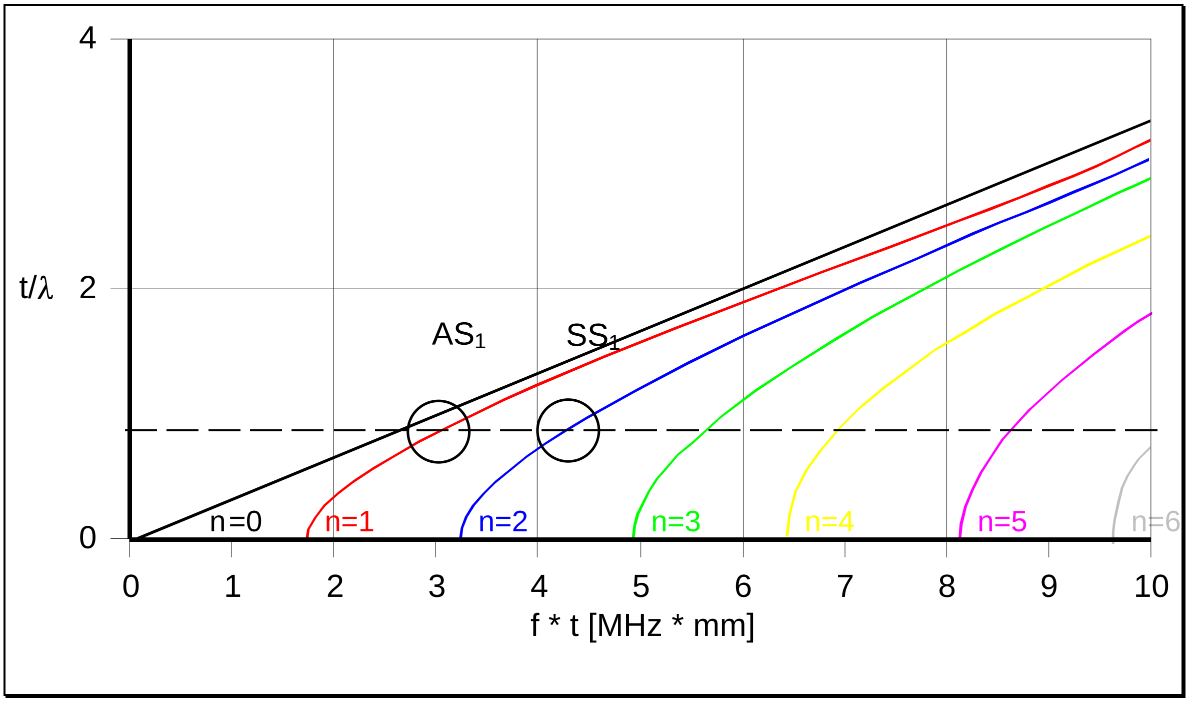


Figure 3: Dispersion Diagram

The lowest mode (***n***=***0***) is of constant velocity independent from frequency and wall thickness and equal to the sound velocity of a bulk shear wave. The velocities of the other SH-wave modes (***n***>***1***) are dependent on the selected frequency and wall thickness of the component to be inspected. This means, that for a fixed frequency the ***n***>***1*** SH-wave modes are reflected by local wall thickness reductions due to a change of the acoustical impedance caused by a local change of the sound velocity in accordance with the dispersion diagram. Other reflectors, such as pitting, cracking, etc., usually cause specular sound reflection or also sound diffraction.

4. SEARCH UNITS AND EQUIPMENT

The theorem of EMAT technology and EMAT search units are described in the respective literature [2,3]. The EMAT search unit consists of a transmitter and receiver coil and an electric or permanent magnet. With a multi-period coil, the ultrasonic wavelength is provided based on its periodicity, and different modes can be easily generated and received by adjusting the frequency of the transmitter current in accordance with the dispersion diagram. Such a search unit can be operated with a small air gap (< 1-2 mm) between the unit and the inspection surface; Therefore, a thorough cleaning of the surface is not required.

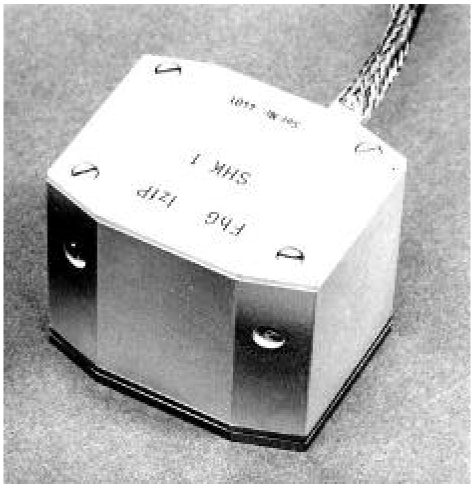


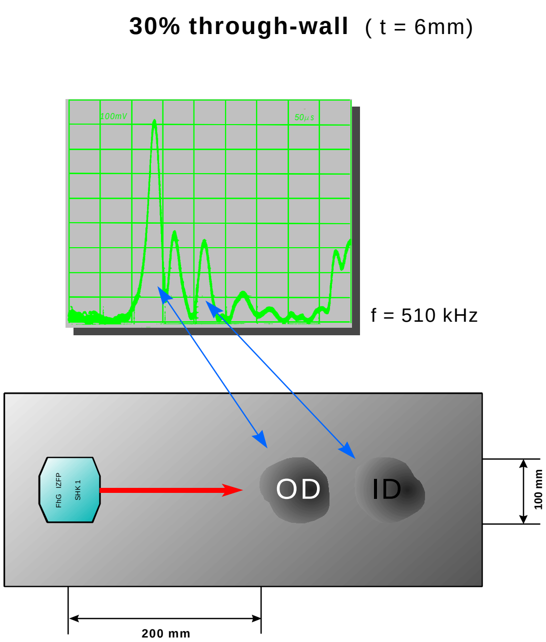
Figure 4 shows a search unit optimized for SH-modes 1 and 2, with a coil periodicity of 8 mm used for plate thickness from 4 to 10 mm. A small electromagnet provides the necessary magnetic induction. Field inspections with this search unit type have been successfully performed.

Figure 4: EMAT Search Unit

Special electronic equipment was developed to operate the search units. For the validation of equipment and technology, field trials on actual tank bottoms have been performed.

5. EXPERIMENTAL RESULTS

Measurements to determine the detection sensitivity have been carried out on different test specimens with simulated wastage, simulated pitting (side-drilled holes with different diameter and depth), and simulated cracking (EDM notches). Specimen thickness was 6 mm and 10 mm respectively . Specimens with real corrosion (wastage) were also available.



SH-wave search units with a coil periodicity of 8 mm were used for the above-mentioned thickness range. Investigation of the detectability of simulated wastage demonstrated highest sensitivities for modes 1 and 2 as depicted in figures 5 through 7.

Figure 5 displays an A-scan (mode 1) and the test specimen with two corroded areas with diameters of about 100 mm, one on the inspection surface (OD), the other on the opposite surface (ID). In both cases the remaining ligament is 70%.

Figure 5: Wastage Detection

SH-Mode SS_1

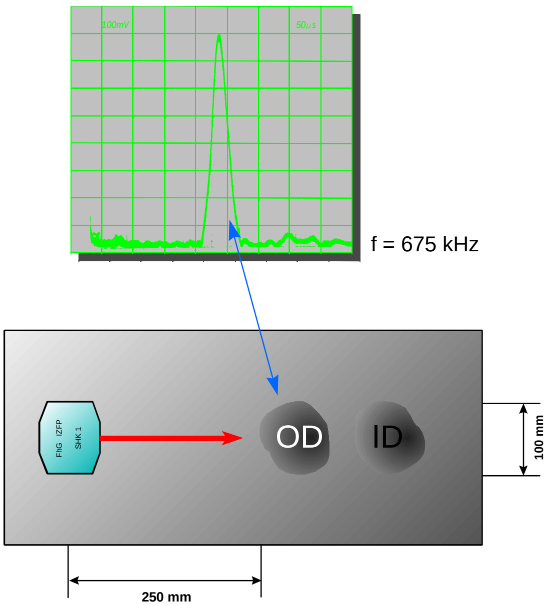


Figure 6: Wastage Mode 2 (SS_1)

The A-scan in Figure 6 shows the signal of wastage on the search unit surface (OD); the flaw on the opposite surface is shadowed by the first reflector and is therefore not detected. This flaw was detected in mode 2 with a signal-to-noise ratio of 26 dB as shown in Figure 6, the surface distance between search unit and reflector is 250 mm.

SH-Mode AS_1

When flaws are smaller in diameter then the lateral width of the effective sound beam, several flaws located behind each other can be detected.

As depicted in Figure 7, two flaws (∅ ≈70 mm) on the near surface and on the far surface with 50 % remaining ligament and located behind each other at a distance of 30 mm, were detected with signal-to-noise ratios of 25 dB and 16 dB. Even at a surface dis-tance of 1 m, the reflector on the near surface was detected with a signal-to-noise ratio of about 20 dB.

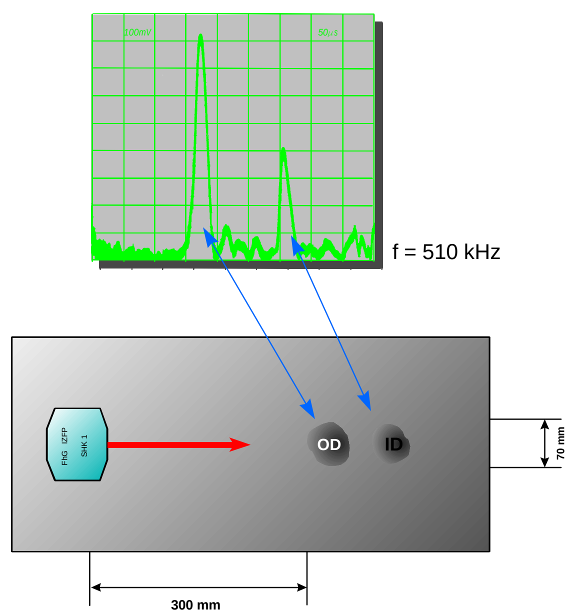


Figure 7: Wastage Mode 1 (AS_1)

SH-Mode AS_1

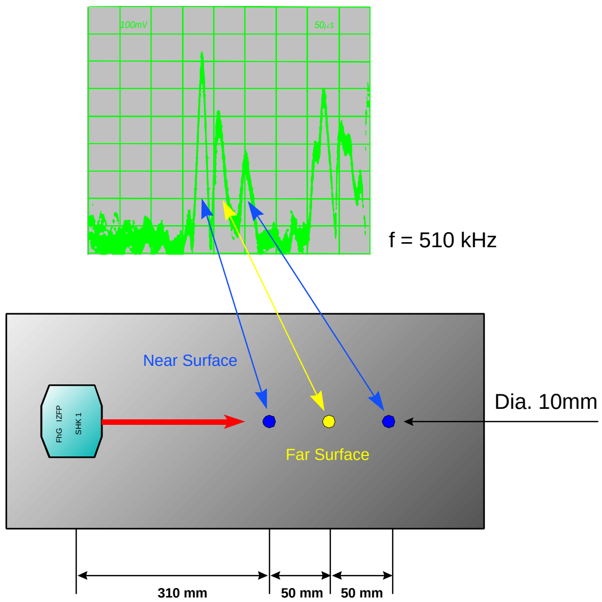


Figure 8: Pitting, Mode 1 (AS_1)

On another sample, pitting-type corrosion was simulated using 10mm diameter and 50% through-wall side-drilled holes (SDH). Three holes were located behind each other, spaced at a distance of 50 mm. The first and third SDH are located on the near surface, the centered SDH is located on the far (back) surface of the specimen. All three reflectors are separately detected (Figure 8) with signal-to-noise ratios of 18 dB and 11 dB respectively.

The last example (Figure 9) shows the signal of a simulated crack-type flaw (EDM notch) with a depth of 1 mm(10% TW) and a length of 20 mm in a 10 mm thick plate. The flaw was detected at a surface distance of 190 mm. The additional signals are reflections from the end (corner) of the specimen. For this larger thickness (10mm) mode 2 (SS_1) was used.

10% through-wall (t = 10mm)

SH-Mode SS_1

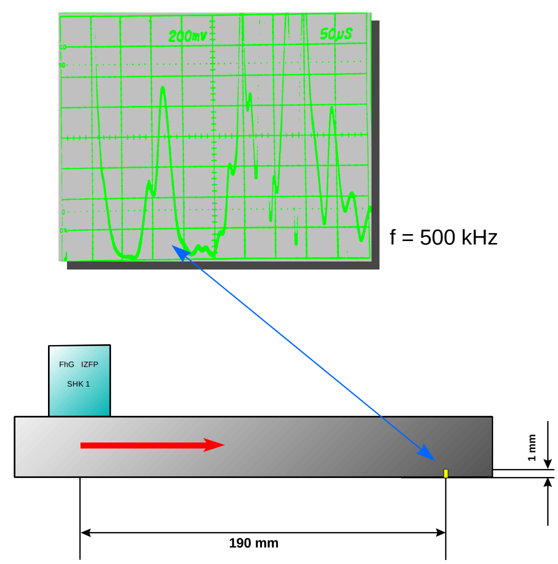


Figure 9: Cracking Mode 2 (SS_1)

Table 1 below summarizes the results of the experiments on different specimens outlining the achieved sensitivities and surface distances which may be anticipated for similar samples.

Flaw Type	S/N Ratio	Surface Distance
Simulated Corrosion Wastage : Remaining Ligament 50-70% Pitting : Diameter 10 mm	25 to 30 dB ≥15 dB	200 to 500 mm 200 to 300 mm
Actual Corrosion Wastage : Remaining Ligament 10-50% Diameter 20 mm	≥15 dB	200 to 300 mm

Table 1: Sensitivity and Surface Distance of SH-wave modes for the detection of corrosion.

6. CONCLUSION

These investigations demonstrated that corrosion in bottom plates of storage tanks can be detected at relatively large surface distances (the distance between the search unit and the reflector) using SH-modes and optimized EMAT search units. This technique can be used to locate corroded areas without dense scanning grid requirements, as are necessary when using conventional ultrasonic thickness gauging. If corrosion is detected (using this technique), wall thickness measurements are carried out to acquire precise thickness values. Using this technique not only significantly reduces inspection time, but it also allows high-speed scanning on surfaces not carefully cleaned prior to the inspection.

This technique is also applicable on piping or vessel components (inspection from either side) using axial or circumferential propagation of the ultrasonic waves.

7. LITERATURE

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