DRY UT BY GUIDED SHEAR HORIZONTAL USING EMAT'S

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Abstract: Ultrasonic Testing (UT) is still concentrated on the 'classical' wave modes generated by piezoelectric probes. Other wave modes as the Shear Horizontal (SH) waves and the wide class of guided waves offer new solutions for UT not yet widely used due to the lack of availability of appropriate probes and equipments.
EMAT's are the most far developed ultrasonic probes for UT using SH-waves and guided waves. Despite their limitations (efficiency, lift off-effect, frequency range etc.) they have the big advantage to perform dry UT.
This contribution will present new solutions for UT of metallic parts using guided Shear Horizontal waves: for the in-line inspection for defects and weld geometry of butt welds, for crack inspection in gas pipelines, for screening UT for hidden corrosion in tubular goods, for long range inspection of pipes and for the inspection of multilayered aircraft components.
The latest developments of the probe design are shortly reported. The equipments and their integration in production lines as well for in-service application are shown together with examples of inspection results during their practical applications.

Introduction: In thin walled plates and tubular goods ultrasonic waves can propagate as guided plate waves in a flat strip or in the wall of a pipe with a radius of curvature large compared with the ultrasonic wavelength (in circumferential as in axial direction). Two types of these waves are existing – the Lamb waves, oscillating in the plane of incidence and the SH-waves polarized perpendicular to the plane of the drawing in Fig.1**.** The propagation behaviour of both polarizations is described by their dispersion diagrams. The dependency of their phase- and group-velocities from thickness t of the plate (resp. of the tube wall) and ultrasonic (US) frequency f is typical for nearly all modes besides the lowest mode SS_0 of SH-waves. This one propagates independent of thickness and frequency with the shear wave velocity of the material. The higher order modes start propagating at lower cut-off-frequencies; with increasing t*f values their velocities approach asymptotically the velocity of the Rayleigh wave (lowest modes of the Lamb-waves) resp. the shear wave velocity of the material.

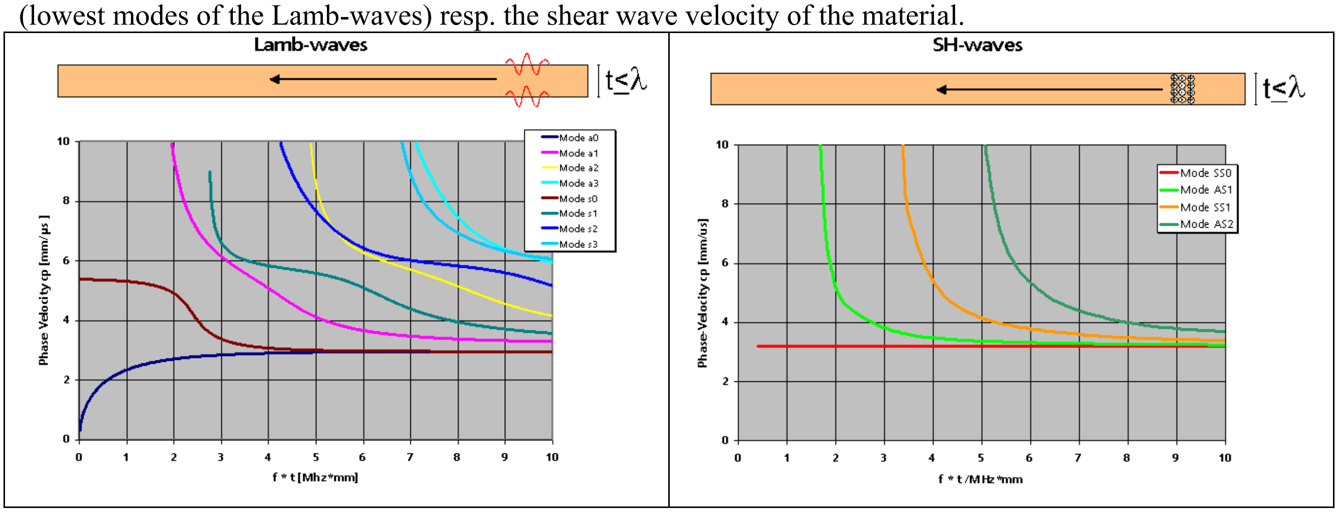


Figure 1: Dispersion-diagrams of Lamb- and SH-modes

The possibility of the use of dispersion-features of SH-modes for ndt purposes will be presented later on by two examples: '**In-line inspection of laser welds of Tailored Blanks'** and **'Monitoring the scrape process of the seam of longitudinal pipe welds'.**

Both wave types can be very efficiently generated and detected by EMAT's. For the most of the applications discussed in this paper two types of transducers are used, which differ from the well known basic principles of EMAT angle probes for SV- waves (Lamb- and Rayleigh-waves) and SH-waves.

The classical design of an EMAT angle probe for Shear Vertical (SV)-waves is to operate a meander-like wounded RF-air coil in a homogeneous magnetic field with perpendicular orientation to the materials surface. (Fig 2a). To improve the mechanical protection of the RF-coils the design shown in Fig. 2b was developed **(/1/)**. In this case the RF-coil is wounded on a comb structure made from layered metallic material with high magnetic induction and permeability and low electrical conductivity. The magnetic RF-field of the coil is amplified due to the magnetic permeability and guided by the teeth of the comb structure to the bottom where the magnetic RF-field induces the eddy currents in the same way as for the RF-air coil. This design has the advantage of a higher ruggedness and a better wear protection of the coils.

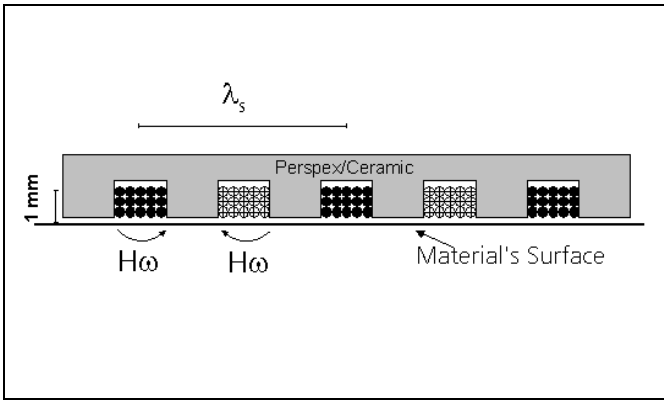


Fig.2a: Meander-like RF air coil

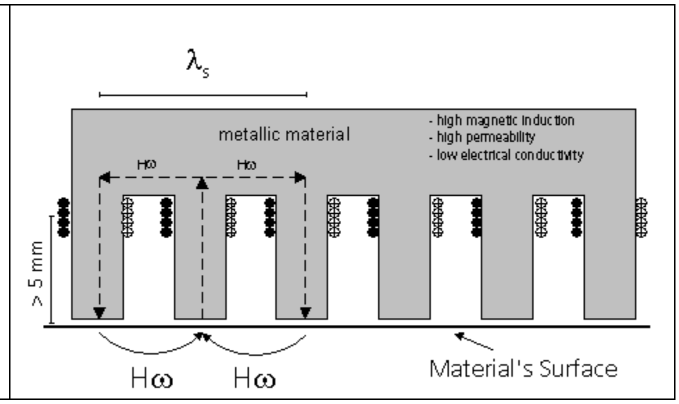
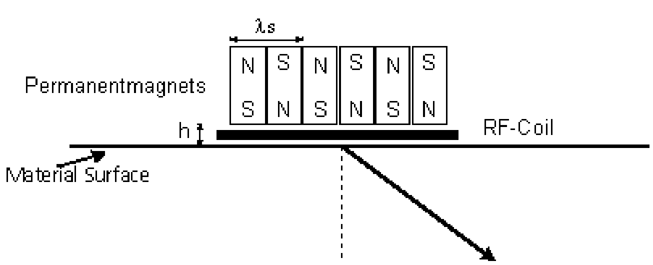


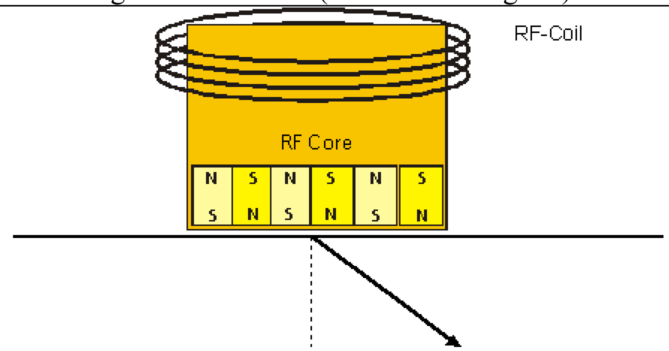
Fig.2b: Meander-like RF coil on a metallic core

For the generation and detection of SH-waves similar solutions were found (/2/) (see Fig. 3). The conventional way of generating SH-waves is to superimpose a spatially homogeneous RF-field induced by flat rectangular coil by a spatially inhomogeneous magnetic field generated by a stack of Permanent Magnets (PM). Fig. 3a shows this design in a side view. The alternative design is explained in Fig. 3b. The RF-Coil is wounded on a toroidal RF-core (made from very thin metal glass strips) (front view of fig. 3b); the RF-current I_ω in the RF-coil induces via the magnetic induction B_ω the eddy currents I_ω in the material. These are superimposed by the magnetic field of the stack of PM and generate in the same way as for the classical design the SH-waves (side view of Fig. 3b).



Side View

The RF-coil is placed very close (≤ 0.5 mm) to the materials surface underneath a periodic arrangement of permanent magnets of alternating polarity (periodicity is λ_s). The angle of incidence α is given by $\alpha = \arcsin(c_S/(\lambda_s f))$ (c_S: Shear wave velocity, f Ultrasonic frequency).



Side View

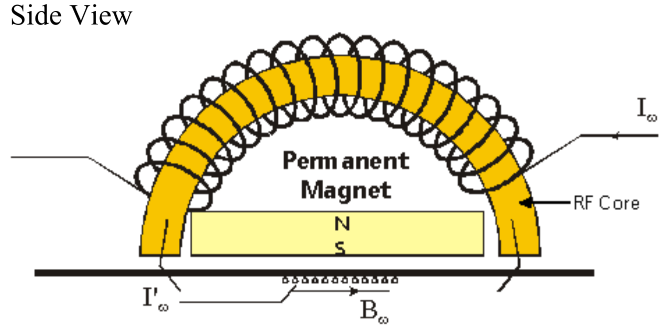


Fig. 3a: Conventional design of SH-wave angle probes Fig. 3b: Alternative design of SH-wave angle probes

In-line Inspection of Laser Welds of Tailored Blanks (/3/, /4/)

For laser welding two blanks to be welded are placed side by side and mechanically fixed. The welding is done without any welding flux. This results in a very narrow heat affected zone (HAZ), which does not significantly change the mechanical and compositional properties of the welded blank (deep drawing property, corrosion resistance). However butt welding by lasers requires a very precise edge preparation of the sheet to achieve a good weld quality. The jointing gap has to be less than 0.1 mm; furthermore a precise positioning of the two blanks and a sufficiently strong clamping of the sheets are necessary. During welding any opening of the jointing gap due to thermal deformation and lateral displacements of the laser spot from the weld position have to be avoided. The process parameters (laser power, welding speed, focal spot of the laser beam, inert gas atmosphere) must be held constant within an optimized process window. By these means butt welding by lasers is a very reproducible technique. However, if any deviations in the preparation of the weld or in the process parameters occur, then typical defects as shown in fig. 4 are the unavoidable results. These defects cannot be repaired and the welded blank has to be scrapped.

Due to large production-volumes the inspection technique has to be integrated into the production process to directly separate defective blanks. The process integration requires an inspection speed of $\geq$ .5 m/s, a signal processing technique that can easily be automated at moderate costs.

The geometry of the blanks favours the application of guided plate waves. These waves are most suited because the whole plate thickness is under vibration detecting surface and internal defects. Tailored blanks are usually composed of sheets of different thickness. Hence within the butt joint there is a thickness step, which can cause additional echoes masking the echoes from defects in the weld. To overcome this problem the non-dispersive mode SS_0 is used.

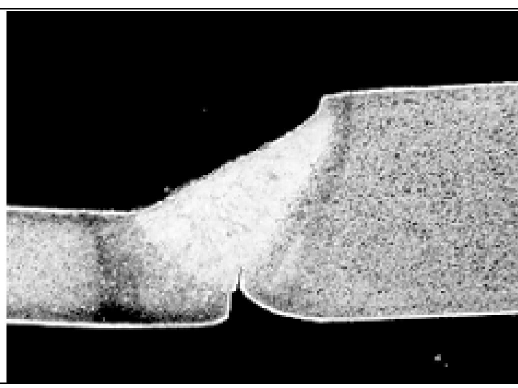


Fig.4a: Laser weld - incompletely through welded

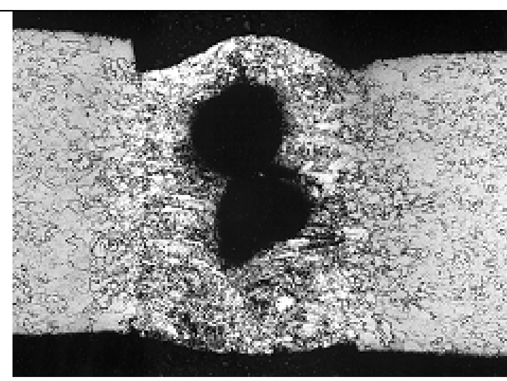
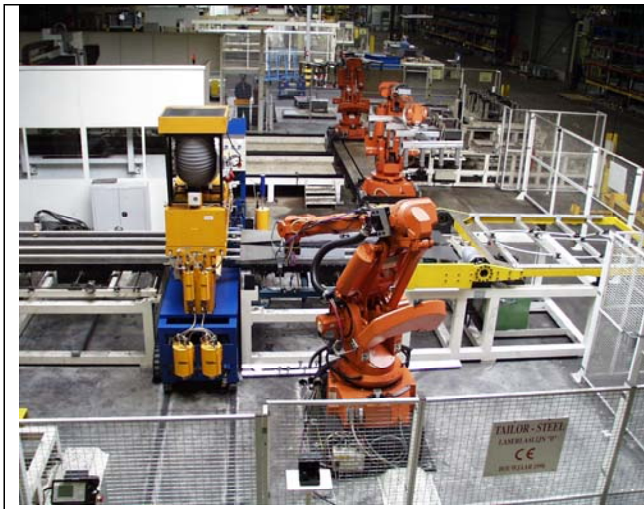


Fig. 4b: Laser weld with internal pore



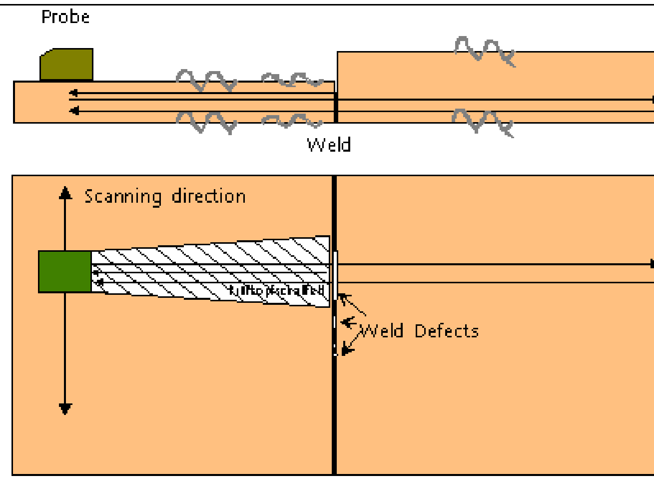
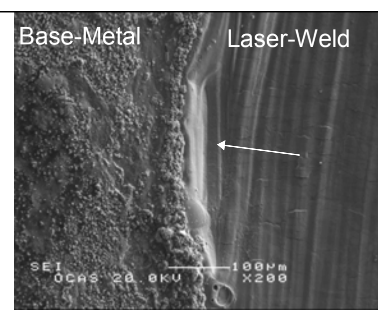


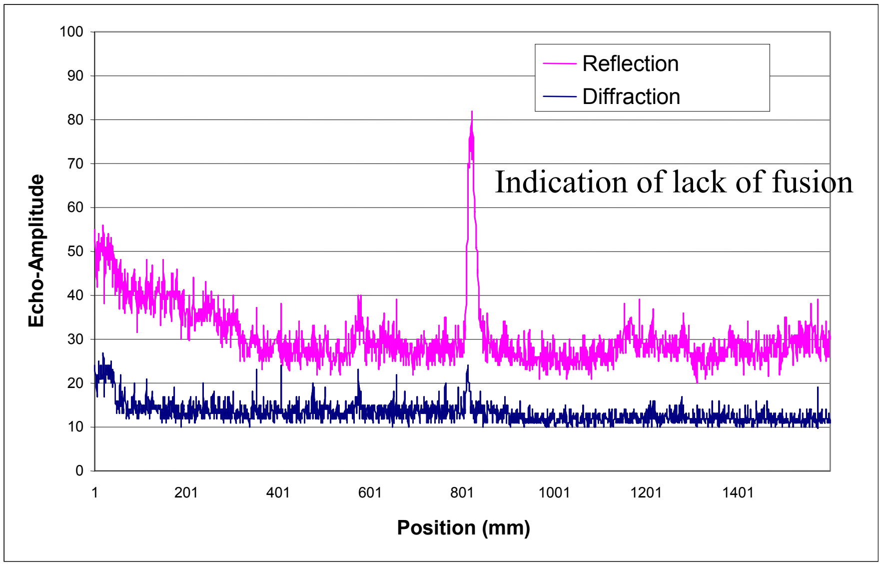
Fig.5: Laser Welding line at ARCELOR MTB

Fig.6: Inspection Principle

The inspection is performed in the pulse-echo technique. According to figure 6 the probe (T/R-type with a focus in a distance of 65 mm) is placed on one of the surfaces of the thinner sheet and radiates the ultrasonic pulse into the weld. Back reflected signals (echoes) from weld defects such as pores, holes, incomplete through-welding… are digitized; the maxima of the echo-amplitudes are displayed versus the probe position as Amplitude-Locus Curves (Scan). Fig. 7a shows such a scan with the indication of an internal lack of fusion between the weld and the base metal of the thicker blank. In Fig. 7b a micrograph of the weld with the lack of fusion and the corresponding TEM exposure are displayed. This example clearly shows the benefit of UT compared to optical techniques frequently used for Tailored Blank weld inspection. None of these techniques would have detected such a very critical internal defect.

The used EMAT-probe (in the central part of the figure) and the probe-holder are shown in Fig. 8a. The probe is fixed in a ground frame; this frame is flexibly connected by four springs with the upper part of the holder, by which the whole assembly is mechanically fixed either with a robot or with the z-axis of a gantry - mowing the probe along the weld - or with an inspection table as a part of a welding line (ThyssenKrupp Tailored Blanks GmbH) as shown in fig. 8b. In this case the probe is fixed and the blank is moved. The probe provides an air cushion by pressurized air leaking from the bottom plate of the probe. The probe glides on the air cushion in a fixed distance of about .2 mm to the blank surface. The counter roller presses the blank against the air cushion of the probe and cares for the necessary constant distance between blank and probe.





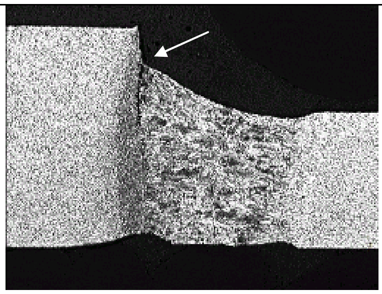


Fig. 7a: Inspection Scan

Fig 7b: Micrograph of the defect

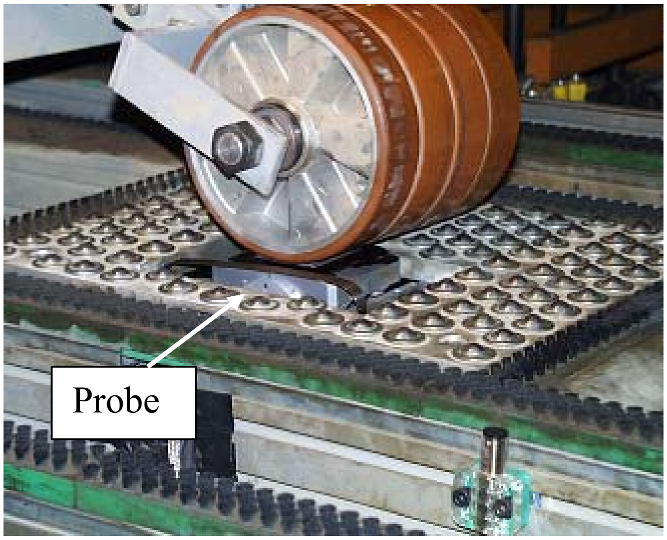


Fig. 8a: Front view of Probe and Probe Holder

Fig. 8b: Probe integrated in the welding line

Monitoring the scrape process of the seam of longitudinal pipe welds (/5/)

Longitudinal pipe welds join also in a butt weld configuration (High frequency induction welding) the two edges of a steel strip preformed to a pipe. Root and crown of the weld are removed after welding by scraping. To monitor the quality of scraping an ndt method is demanded which is capable to deliver information about the local wall thickness within the weld region. The dispersive SH-mode AS_1 detects such local changes of the wall thickness because the acoustical impedance is different from that of the wall out of range of the weld seam. This difference of the acoustical impedance results in echo signals from the weld.

The inspection principle is illustrated in fig. 9**.** It is based on a combined evaluation of the pulse-echo- and pulse transmission inspection using the dispersive SH-mode propagating in circumferential direction of the pipe wall. The inspection frequency is 0.8 MHz. The echo- and roundtrip signals are gated out electronically. Their maximum is displayed on-line as scan (see fig. 11). Fig. 10 shows in the foreground the tube; the weld is in the 12 o'clock position. At the backside the probe holder is located; the probe is (hidden by the tube) fixed in the central part of the holder. The tube is moving along the probe in a fixed distance of 0.2 mm (assured by the holder rollers) with a speed of up to 1m/s.

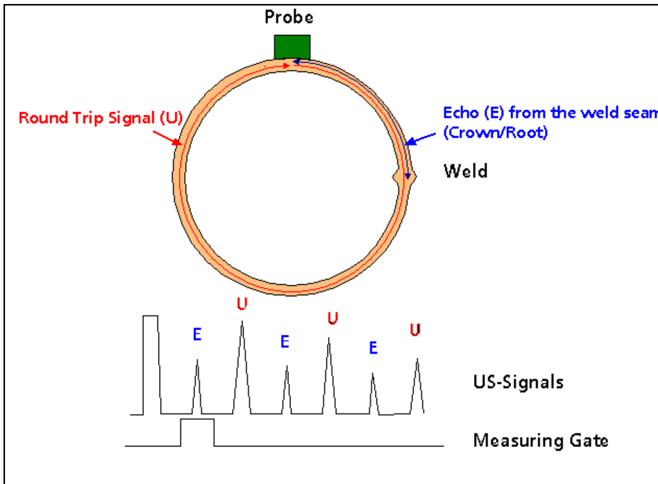


Fig.9: Principle of monitoring the scraping process

Fig. 10: Probe Holder and tube in the welding line

In the figures 11a and b dumps of the software menu which shows (in the white window) the US-scans of a 16 m long weld. The curves represent the echo maxima of a well scraped weld (right) and of a very badly scraped weld. The well scraped weld shows a very low amplitude level along the whole 16 m; whereas the scan of the badly scraped weld has a much higher amplitude level. The oscillations in the first 7 meters show a periodic change of the quality of the scraping. In the second half of the scan the decreasing level indicates a slow increasing of the scraping quality.

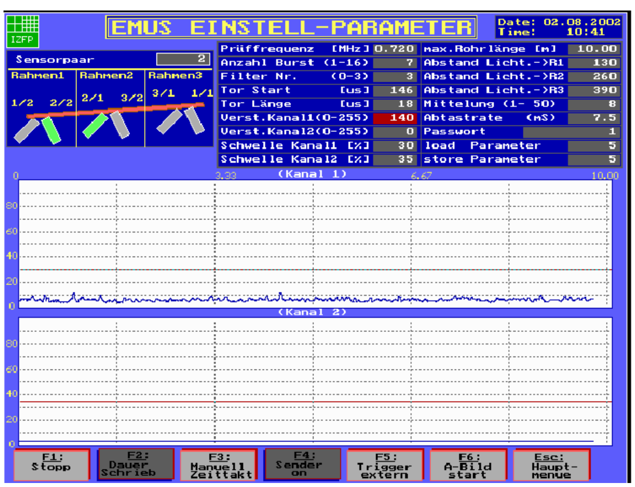


Fig.11a: Scan of a well scraped weld

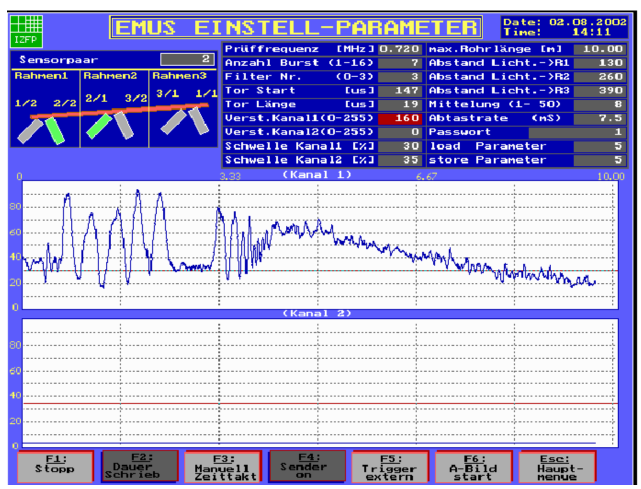


Fig. 11b: Scan of a badly scraped weld

Gas-Pipeline Intelligent Pig EMATScan® CD

Worldwide the integrity of Oil- and Gas-Pipelines is of high importance as well due to economical but also due to safety- and environmental protection reasons. To assure this integrity ndt-inspection tools (Intelligent Pigs) are used, which move with the stream of the medium through the pipeline. The Magnetic Flux Leakage (MFL)-technique is the most common technique as well for corrosion inspection as for the detection of (longitudinal) cracks for oil- and gas-pipelines. It is well known that UT is much better suited than MFL for corrosion testing and crack inspection, esp. for outside corrosion and cracks. For oil-pipelines UT tools for corrosion inspection are in operation since 2-3 decades, for crack detection since about 10 years. For Gas-Pipelines Ultrasonic Inspection Tools are not yet wide spread due to the difficulties of dry coupling using conventional piezoelectric probes. There are some realizations by wheel probes. The potential of EMATs of dry UT is obvious; however their operability in a pipeline at inspection speeds of up to 2m/s had to be investigated under many aspects, esp. the number of probes for full coverage of the circumference, the amount of electrical power for their operation by batteries, lift off and wear of the probes.

Within a feasibility study it was shown that guided SH-waves propagating in the pipe wall in circumferential direction have a very high sensitivity for longitudinal crack-like defects and crack fields (SCC) independent from their location (outside or inside). Furthermore it was shown that by proper selection of the US-frequency the whole circumference of e.g. a 36” pipe can be covered by few SH-wave probes. By additional use of Rayleigh waves propagating at the inside surface as well discrimination between inside and outside defects as a defect sizing based on amplitude criteria is possible. Based on these results the concept of the EmatScan CD was developed. In close cooperation with the customer **PII Pipetronix** the pig was manufactured and tested.

Fig. 12 shows the final version of the SH-wave probe with optimized wear protection together with a spring loaded suspension. The probe is constructed using the principle of fig. 3b.

Fig. 12: SH-wave probe

Fig. 13: EMATScan CD during preparation of a test run

The pig was completed in 2002. It is shown in Fig. 13 during the preparation of a test-run. On the right side of the figure the probe compartment is located. One set of the SH-wave probe (Transmitter and Receiver) can be seen at the top of the compartment.

Conclusions: The presented practical examples show that guided SH-waves offer a couple of new possibilities for non-destructive testing. Due to the availability of practically proven EMAT-Probes the use of these wave types isn’t more restricted to laboratory applications.

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