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W. A. K. Deutsch, M. Joswig, V. Schuster, M. Lach

Summary

This article contains a brief overview on the automated full-body inspection of tubes. For the on-line inspection, two systems are presented. The HRP-system is suitable for the diameter range up to 170 mm. Key property is the unmatched through-put rate. Larger diameters can be inspected with the RPS-system where the tube is inspected in partial immersion and in helical test traces. If an additional pipe end inspection is required, the REPA-system is used. The RPT-system is appropriate for an off-line inspection, again in helical test traces. The mechanics consist of a testing traverse and compact multi-probe holders.

Systems for the Ultrasonic Inspection of Tubes

W. Deutsch, M. Joswig, V. Schuster, M. Lach

KARL DEUTSCH Instruments, Sensors & Systems for NDT, Wuppertal, Germany

info@karldeutsch.de, www.karldeutsch.de

This article presents various concepts about the full-body inspection of tubes. KARL DEUTSCH has extensive experience with the automated inspection of tubes [1]. All systems are completely developed in Wuppertal and offer a turn-key solution for the customer. The typical customers are the steel manufacturers so that the systems are designed for a rough industry environment.

A complete line of weld testing systems for tubes is also available from KARL DEUTSCH. SAW- and ERW-tubes require different system set-ups and custom-made probe carriers. These systems will not be considered in this article.

Tubes in the diameter range from 20 up to 170 mm can be inspected with the HRP-ECHOGRAPH system. The biggest advantage of this system is the high through-put rate of up to 2 m/s which is achieved by avoiding any mechanical rotation. The circumference of the pipes is surrounded by stationary probes. The type and orientation of the probes allow for the detection of longitudinal and transverse flaws. In addition, a wall thickness measurement and a test for laminations is carried out. A precise evaluation of the flaw length is much more reliable than with any rotational system. Also, the detection of short flaws is a strong point of a stationary system.

Large tubes with diameters up to 610 mm can be inspected in partial immersion with the RPS-ECHOGRAPH system. Water-filled test chambers are located underneath the tubes and hold several probe batteries. While the probes remain fixed, the pipes move along the test chambers with a helical motion. Again, various probe orientations lead to the detection of all flaw types and a measurement of the wall thickness. For a rotational inspection, the goal is to produce wide test traces for a high through-put rate. This is achieved by using special-made probe batteries which hold several probe elements in one housing while the gaps between the elements should be kept as narrow as possible. Due to natural focusing at the near field length of a probe, small untested areas remain between the individual elements. In a co-operation between KARL DEUTSCH and Vallourec & Mannesmann Tubes, new probe batteries have been developed which avoid those gaps. The idea is to produce an electronic overlap by exciting two neighbouring probe elements at the same time. In the next test cycle, the active zone (consisting of two elements) is moved by one element.

The third type of tube inspection system is the RPT-ECHOGRAPH. This system is especially suitable for an off-line inspection. It consists of a testing traverse and several multi-probe carriers. The tubes are loaded with a transverse conveyor system. Once the tubes are in the testing traverse, rollers put the tubes into rotation. The number of probe carriers is chosen in accordance with the desired through-put. They are linearly moved along the tube and inspect the tube in the 12 o'clock position. Rotational and translatory movements result in helical test traces. Each probe carrier holds up to five probes for the combined inspection for laminations, longitudinal and transverse flaws. The coupling is achieved with guided water jets. An extension to also detect oblique flaws with two extra probes in the same carrier has also been realised.

Finally, a tube end inspection can be carried out with the REPA-ECHOGRAPH system. Again, this is an off-line inspection where the tube ends are inspected in helical test traces. The principle is very similar to the RPT-system, although the mechanical frame is much simpler because only a short portion of the pipe has to be inspected (approx. 50 mm on each end). Probe carriers ride on top of the pipe and the ultrasound is coupled with guided water jets.

The evaluation of the ultrasonic signals is carried out with the digital ultrasonic electronics ECHOGRAPH 1155. The electronics can be programmed according to the testing task such as the inspection of bars, pipes, rails, billets or gas containers. In general, a multitude of channels is necessary and each channel can be individually configured. As a supplement to the electronics, a data management system (type DAV) is provided. The DAV is used to process the test data according to the customers needs. Test protocols are generated, the test parameters are stored

for quick retrieval and therefore for short change-over times. The current version of the DAV is based on the operation system Windows and allows for a convenient operation of the system.

1 Full-body inspection of tubes with curved foil probes (system HRP)

Many ultrasonic systems for the tube inspection use probe which rotate around the linearly transported specimen. This approach has two major disadvantages. The linear movement of the tube is rather limited in order to perform a 100%-inspection with helical test traces. The rotational movement and linear transport of the tube have to be correlated which is difficult to achieve, since most conveyor systems introduce slip. The second drawback is the mechanical wear due to the rotation. Modern systems work with a rotational speed of several 1000 rpm and worn-out mechanics can lead to pseudo-indications. Rotational systems are more sensitive against dirt in the coupling medium and have shown problems with testing black material.

A HRP-ECHOGRAPH inspection system uses stationary foil probes. Special treatment of PVDF-foils lead to extraordinary piezoelectric properties [2]. A low acoustic impedance suggests their use for immersion testing. Just recently, this patented system type was extended to detect all flaw types [3]. Laminations, longitudinal and transverse flaws are detected with a test speed of 2 m/s. A supervision of the tube profile is included by measuring wall thickness and diameter.

The key-modules of the HRP-inspection system are the test chambers [4]. If all flaw types are to be detected, 56 test channels in four immersion test chambers are implemented. Each test chamber can hydraulically be moved between the test position and the calibration position. Calibration and service work can be carried out without disturbing the on-going production. Four triple-rolling drivers move the tubes through the test chambers, but double-rolling drivers can also be used for the feed. The entire system is installed on a test support which is vertically adjustable in order to compensate height differences between testing system and the connected conveyor systems for various tube diameters. The high frame (Fig. 1) carries remote pulser-receiver units which connect to the probes via short cables. A flaw-marking device (up front in Fig. 1) marks the location of detected flaws with high accuracy. The knowledge about the flaw locations can be used for a manual post-inspection. The flaw locations are also documented in the test reports.



Figure 1: Full-body tube inspection with the HRP-System with a testing speed of up to 2 m/sec.

Probe caskets which carry the probes are inserted into the immersion test chambers. The test chambers are equipped with extremely fast closing mechanisms in order to produce short untested ends. During opening and closing of the chambers only little water is lost. The opening moment is precisely chosen to prevent water from

entering the tube thus avoiding pseudo-indications from the water. Conventional systems require a closing of the pipe ends with plugs which is not necessary with the HRP-System.

The probe caskets are optimised for their respective inspection task. The orientation of the foil probe allow for the detection of longitudinal and transverse flaws. The on-line supervision of the profile by measuring diameter and wall thickness is carried out with conventional immersion type probes in eight test traces around the circumference.

Changes of the tube dimension require the adjustment of the closing mechanisms. Small diameter changes can be adjusted for by replacing the guiding nozzles. Big differences in diameter result in changing the probe casket. A lifting gear is supplied for the comfortable change of the caskets (Fig. 1). A casket change is necessary in order to keep the water path between probes and specimen in the same order. Each probe covers 30 degrees of the circumference and for growing diameter, larger probes are necessary (Fig. 2). The curvature of the probes produces a very regular sound field geometry inside the specimen.



Figure 2: Foil-probes for the inspection of round profiles, various sizes to inspect large range of specimen diameters.

A total of 32 foil probes in two test chambers is used for the detection of longitudinal flaws. Ultrasound is transmitted in the circumferential direction of the tube. According to the standard test specifications, both circumferential directions are required. Therefore, the probes in one test chamber transmit in the clockwise direction, the probes in the second chamber are responsible for the counter-clockwise direction. The caskets which hold the probes in the test chambers carry a total of 16 probes in two layers of 8 probes each. The probes from the second layer close the gaps from the probes in the first layer (Fig. 3). Each probe covers 30 degrees of the circumference, meaning that 16 probes guarantee a 100% inspection with sufficient overlap. The adjustment of the incidence angle is centrally adjusted for all probes of a casket. An adjustment spindle with a calibrated position gauge allow for reproducible angle settings.

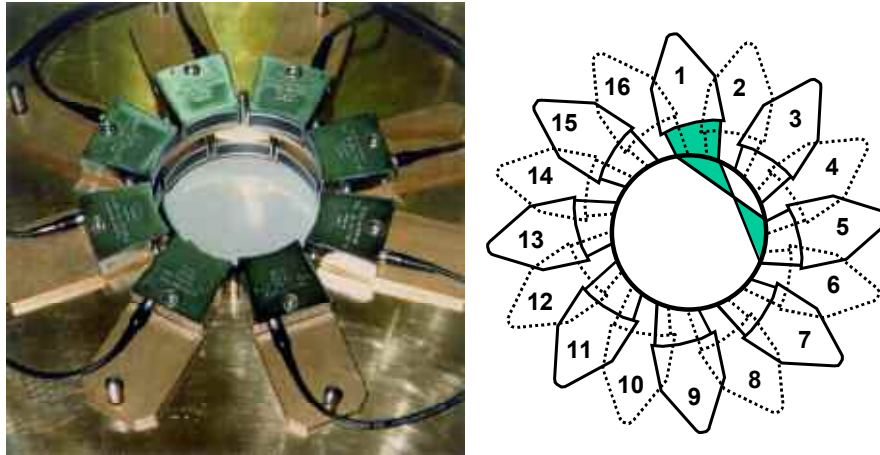


Figure 3: Probe casket with 16 probes for the inspection for longitudinal defects, central adjustment of the incidence angle for all probes is integrated.

The detection of transverse flaws and the wall thickness measurement is performed in the remaining test chambers. Sixteen foil probes are sufficient to offer a 100%-inspection for transverse flaws. The probes are tilted with respect to the pipe axis, half of them shooting into the transportation direction of the tube, the other half shooting against the transportation direction.

The wall thickness is measured with eight probes in linear test traces. Conventional immersion type probes with round ceramic elements are used. A large bandwidth results in a high resolution and therefore, precise measurement results. The signals from two opposite probes are used to measure the tube diameter. The water path between probe and tube is measured for both probes. The diameter is then calculated from the known position of the probes with respect to each other.

2 Inspection of large-diameter tubes in partial immersion (system RPS)

Tubes with diameters ranging from 15 mm up to 610 mm can be inspected with the RPS-ECHOGRAPH system (Fig. 4). Various mechanical set-ups are available in order to cover the diameter range required by the customer. The inspection with such a system requires a helical movement of the tubes while test chambers with the probes are located underneath the specimen. The test chambers are water-filled for the coupling. Helical test traces are therefore produced. The pitch of the helix has to match the width of the generated test traces in order to guarantee a 100%-inspection. The width of the test trace corresponds to the sound field generated inside the specimen which is dependent on probe frequency and dimension.

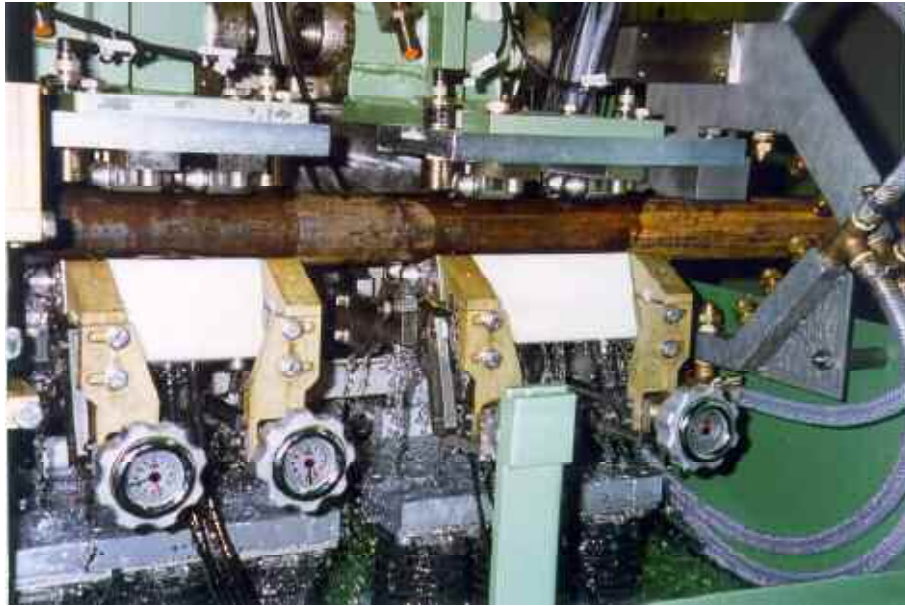


Figure 4: Inspection of large pipes in partial immersion in two test chambers and multiple probe batteries.

For high through-put rates, wide test traces are desirable. This is achieved by using multiple probes and electronic channels for the same testing task. The probes are usually mounted in a common housing in order to minimise the mechanical gaps between the individual elements. Such structures are called probe batteries (Fig. 5). No matter how close the elements are mechanically located next to each other, small areas with low sensitivity will occur due to the natural narrowing of the sound beams at their near field length. The maximum amplitudes are observed on the main axis of the sound beams. Figure 6 shows a c-scan of such a probe battery with six elements. The test reflector is a steel ball with a diameter of 8 mm which is immersed in water. The water path between probe elements and reflector is 240 mm. The test frequency is 2 MHz and the element sizes are 20 by 18 mm. A cut through the c-scan clearly demonstrates the gaps between the elements which are as large as 16 dB. Thus, small defects might be missed in an automated inspection where pre-set amplitude thresholds determine the smallest detectable flaw size.

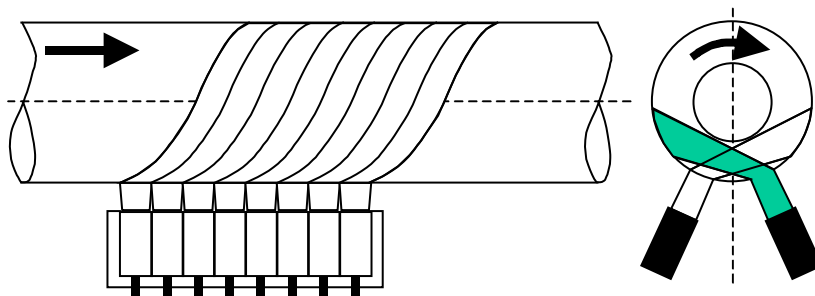


Figure 5: Principle for the inspection of pipes in immersion testing (longitudinal flaws), probe batteries produce wide test traces.

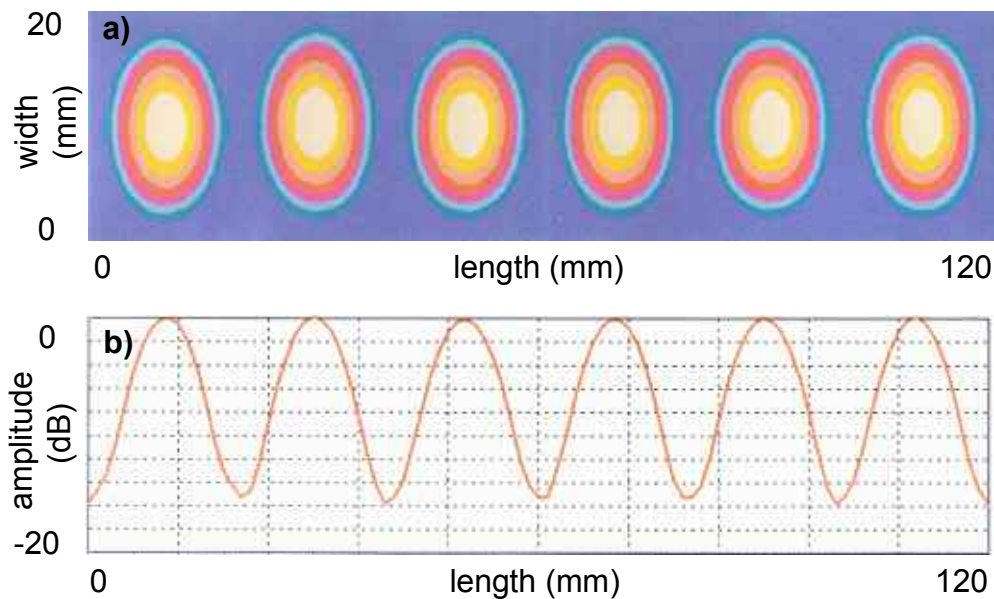


Figure 6: a) C-scan of a conventional probe battery, b) cut through c-scan showing the gaps between the elements.

A practical solution of this problem was developed in a co-operation between *KARL DEUTSCH Wuppertal, Vallourec & Mannesmann Tubes Düsseldorf*, and the *Mannesmann Research Centre (MFI) Duisburg* [5]. A new probe battery with an integrated electronics was designed to replace the existing probe battery. A main goal of the project was to keep the existing mechanical set-up and also the existing ultrasonic electronics. The newly developed electronics act as an internal switch and activates two neighbouring probe elements during each test cycle. The two active elements are toggled through the battery and overlapping sound fields are the result. Naturally, the number of elements has to be increased by one compared to a conventional battery. Figure 7 demonstrates the use of a 7-element battery during six test cycles.

A c-scan for the new probe battery with integrated electronics is shown in Figure 8. The amplitude gaps between the elements along the main axis are reduced to 6 dB which is sufficient for an automated inspection.

The integrated electronics uses state-of-the-art components mounted in smd-technique which results in a compact layout. This was important because the electronics then fit into the housing of the conventional probe battery and the probe holders remain unchanged (Fig. 9). An integration of the new components is easily possible in all ultrasonic systems with such probe batteries. A practical test of the new probe batteries of more than one year proved the reliability of probes and electronics. An award for the best poster presentation was handed out to this project at the 1999 NDT-conference in Celle, Germany.

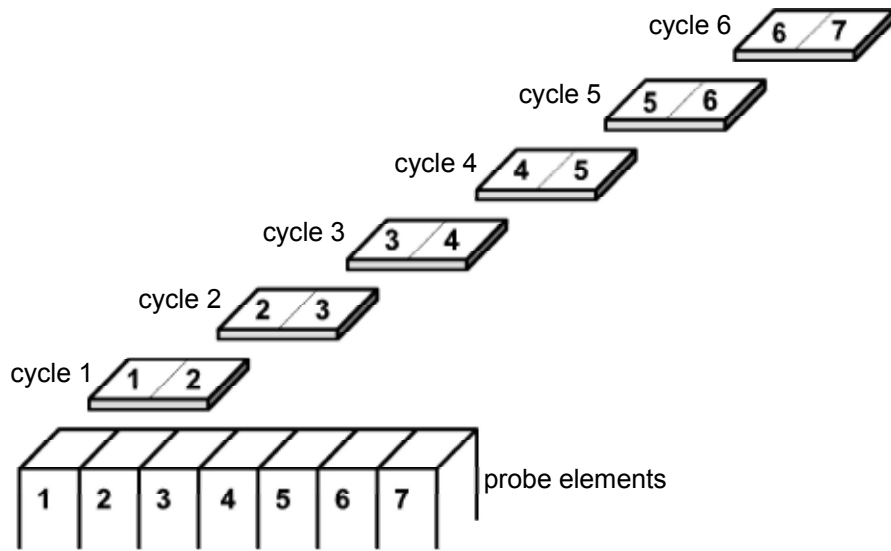


Figure 7: Probe battery with 7 elements, consecutive cycles use two neighbouring elements resulting in overlapping sound fields.

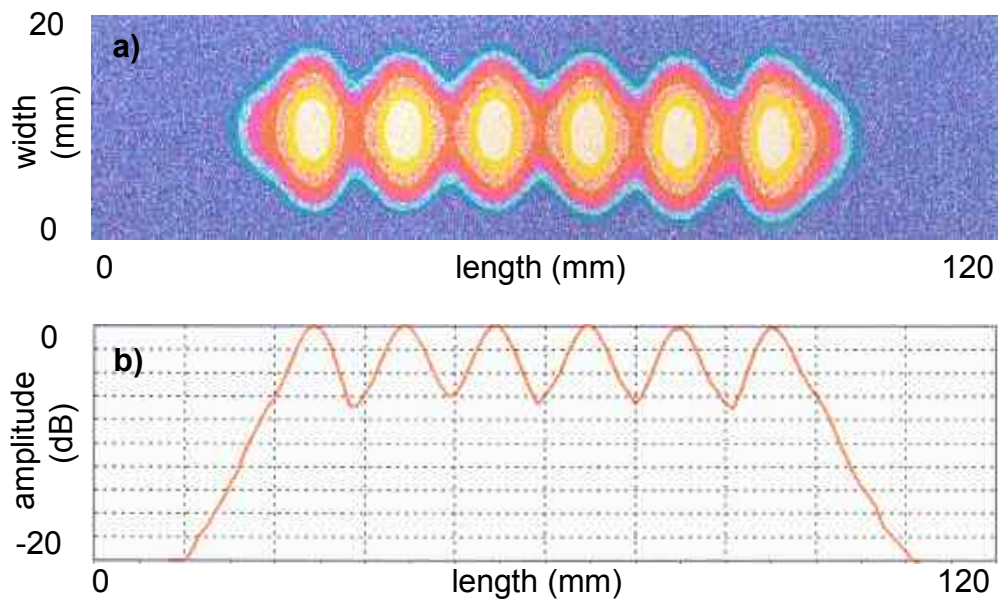


Figure 8: a) C-scan of newly developed probe battery, b) cut through c-scan showing improved sensitivity behaviour (smaller gaps) between the elements.

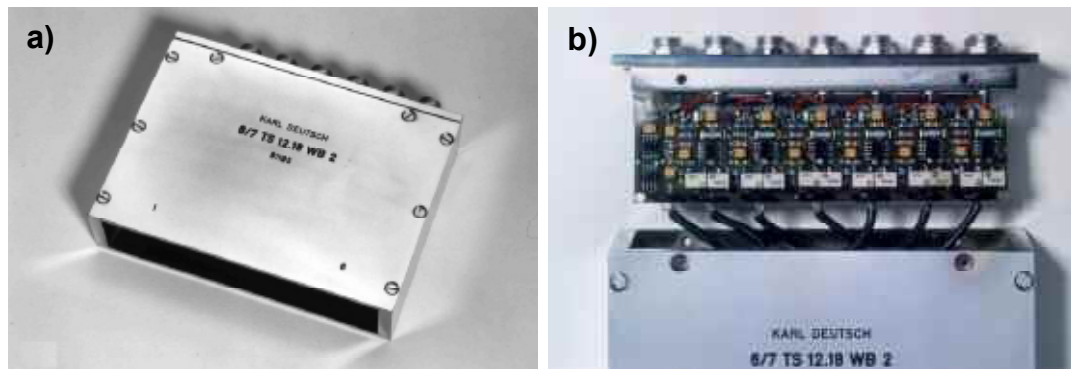


Figure 9: a) new probe battery (with same housing as old battery), b) integrated electronics produce electronic overlap.

3 Off-line inspection of tubes with a testing traverse (system RPT)

The tubes are transported into the testing traverse with a transverse conveyor system. The length of the testing traverse is sufficient to carry the entire tube. Rollers support the tube and put the tube into rotation. A sledge which carries the probe holders is fixed to the mechanical frame of the traverse. The probe holders can be moved with a predefined speed along the rotating tube resulting in helical test traces (Fig. 10).

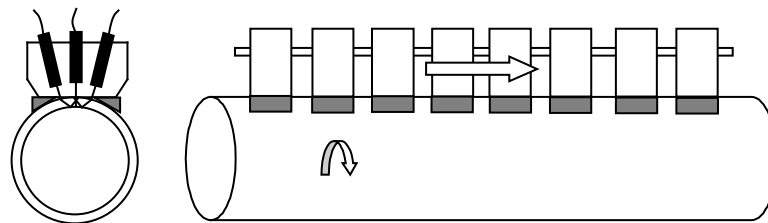


Figure 10: Principle of a testing traverse for tube testing, a rotating tube and linearly moved probe holders produce helical test traces, multiple probe holders increase through-put.

The through-put rate can be increased by using several probe holders. Usually, only one sledge is used which travels along the entire tube. The traces of the individual probes then interleave for a complete inspection. The other possibility is to have several moving sledges and each sledge is responsible for a section of the tube.

Probe holders with many possible probe orientations and for various specimen geometries have been developed [6]. In general, water jet coupling is used to achieve test results comparable to immersion testing. Water jet coupling is superior to the conventional water gap coupling and it allows for the combined inspection of several flaw types with the same compact probe carrier (Fig. 11). Initially, these multi-probe holders were used for the inspection of gas containers where the testing standards require the detection of laminations, longitudinal and transverse flaws [7]. For the case of tube inspection, the detection of longitudinal flaws might be considered sufficient.



Figure 11: Test traverse for tube testing, a) traverse with multi-probe holder for lamination testing, b) multi-probe holder for the simultaneous testing for all flaw types (longitudinal, transverse & laminations).

4 Tube end inspection (system REPA)

The concept of the pipe end inspection is very similar to the RPT-system. Instead of a testing traverse, a cantilever beam is supplied. A conveyor system places the tube underneath the v-shaped probe carrier which is then lowered pneumatically. The probe carrier rides on top of the tube with hardened skids and a helical scan is performed. The system shown in Figure 12 has two probes which detect longitudinal flaws.



Figure 12: Pipe-end inspection, a) lifted probe holder above tube, b) lowered probe holder during test of rotating tube.

5 Processing of the Ultrasonic Data (ECHOGRAPH electronics)

Signals from all channels are processed in real-time. Each channel is equipped with four gates and with up three thresholds. Gates and thresholds can be individually set for each channel. A fast programmable DAC is implemented which compensates the acoustic damping for increasing travel time. Again, the DAC can be differently programmed for each channel. The result is a very even testing sensitivity.

An electronic module (STE) is responsible to combine the ultrasonic data and the data from the position sensors which record the relative movement between probe(s) and specimen. The data management system (DAV) now produces a complete report of an orderly inspection. The DAV consists of a special-made software which is designed for a standard personal computer. The specimen is subdivided in so-called test intervals where the spatial resolution can be chosen. The customer decides on the type of documentation and on the amount of data which has

to be stored. Graphical documentation, tabulated text and a statistical evaluation of the test data is possible. A graphical documentation is available for each specimen and it contains the recorded amplitudes and / or travel times with respect to the test location. The thresholds are marked and overshooting is clearly seen. A statistical evaluation contains data, e.g. for an entire batch or working shift.

The current version of the data management system is based on the operating system Windows NT. A data transfer to a remote host computer or export of ultrasonic data into other Windows-based software is easily possible. The set-up and operation of the inspection system is done with the PC of the data management system. In a rough industry environment, the ultrasonic electronics can also be located in a test cabin. Using the remote pulser-receiver units allows for cable lengths up to 30 m between system and electronics.

6 Summary

This article contains a brief overview on the automated full-body inspection of tubes. For the on-line inspection, two systems are presented. The HRP-system is suitable for the diameter range up to 170 mm. Key property is the unmatched through-put rate. Larger diameters can be inspected with the RPS-system where the tube is inspected in partial immersion and in helical test traces. If an additional pipe end inspection is required, the REPA-system is used. The RPT-system is appropriate for an off-line inspection, again in helical test traces. The mechanics consist of a testing traverse and compact multi-probe holders.

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