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Automated Ultrasonic Inspection

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W. A. K. Deutsch

Summary

This article contains a brief overview on automated ultrasonic inspection of various specimens. The most common applications are discussed. Many other system configurations and testing tasks have been automated. Most of them are based on the principles discussed in the paragraph on coupling techniques. The automated inspection is quite different from the manual inspection: the test traces are predefined and flaw echoes can not be maximised by small movements of the probe. On the other hand, the subjective influence of the operator is ruled out, leading to reliable test results. Also, high quantities of specimen are more reliably tested with an automated test procedure.

Automated Ultrasonic Inspection

Wolfram A. Karl Deutsch

KARL DEUTSCH Instruments & Systems for NDT, Wuppertal, Germany, <http://www.karldeutsch.de>

1 Introduction

This paper discussed various applications where the ultrasonic inspection is carried out in an automated manner. Typical applications, where high through-put rates with sturdy system set-ups are mandatory, are the inspection of tubes, bars, billets and rails. Strip inspection and gas containers are common requests. Typical sites for the operation of automated inspection systems are steel and aluminium production plants and works where such products are further-on processed.

In many cases, the ultrasonic inspection is integrated into the production process and should not limit the output of the production line. Also, several testing systems can be applied in sequence. The operation of an eddy-current system for the detection of surface cracks in combination with an ultrasonic system for the detection of internal defects is often found.

The design of automated systems is always adapted for the respective inspection task. The main goals are the highest-possible coverage of the inspected profile, a high through-put rate, high sensitivity for small defects and high repeatability. Testing protocols are produced and document the proper inspection and all test parameter settings, such that faulty specimens and faulty system operation can later be traced back.

Non-destructive testing is an important part of a quality management system which controls all involved productions processes. In general, the production process is well organised such that high quality is produced. But it has to be possible to track systematic faults during the production, e.g. due to wear in the production tools. A second goal is to detect those defects which still occur even if the production process is stable. The stress on the materials steadily grows and the size of defects which have to be detected decreases. On the other hand, all testing methods have physical limitations. For instance, the ultrasonic wavelength limits the minimum flaw size which can be detected. But the ultrasonic wavelength can not be lowered without limiting the penetration depth of the ultrasonic waves. Therefore, it has to be the goal of system operators and system manufacturers to push the physical limits little by little.

If the zero-defect-philosophy can ever be reached remains questionable! A first step would be, if operators and manufactures could agree on useful standards which clearly demonstrate the capabilities of automated testing systems. This remains difficult while most testing standards were made for manual inspection routines. The defined calibration routines often represent a difficulty for automated testing systems. One example is the ultrasonic bar inspection where flat-bottom-holes are not suitable judging on the dynamic operation of a system. Axially drilled holes are more practical, but are not mentioned in the testing standards.

2 Coupling techniques

Since air is a bad conductor for ultrasound, water is commonly used for the ultrasonic coupling. This usually governs the design of every testing system. The principal ways to couple ultrasound into the specimen during an automated inspection are now discussed:

Immersion testing is a very common method for smaller specimens. Usually the entire specimen is immersed in water and a stage carrying the ultrasonic probes is moved along the specimen. The scanning routines can be more or less automated depending on the desired through-put. The degrees of freedom for moving the probes is mainly governed by the geometry of the specimen. In most cases, an x-y-scan are performed which results in a test report such as a C-scan. For an on-line inspection of long profiles, the immersion technique presents the difficulty to keep the water chamber filled while the specimen is entering and leaving the chamber. Other coupling methods are therefore mainly used.

Partial immersion means that only the bottom of the specimen is immersed in water. This technique is often used for tube and bar inspection. Since only a small portion of the specimen is immersed, only this portion can be inspected at a time. A rotational inspection is commonly used to produce full coverage during the inspection.

If specimens have considerable straightness deviations (e.g. billets), it is advisable to guide the probes along the specimen profile. Special probe holders have been designed and a commonly used technique is gap coupling. The probe holders rest on the specimen surface with a skid which is wear-resistant. A dual-element probe is used and the distance between probe surface and specimen surface is approx. 1 mm. The design of the probe holder is simple but wear of the skids and the danger of damaging the probe (high temperature or loose scale on specimen) has led to more sophisticated solutions.

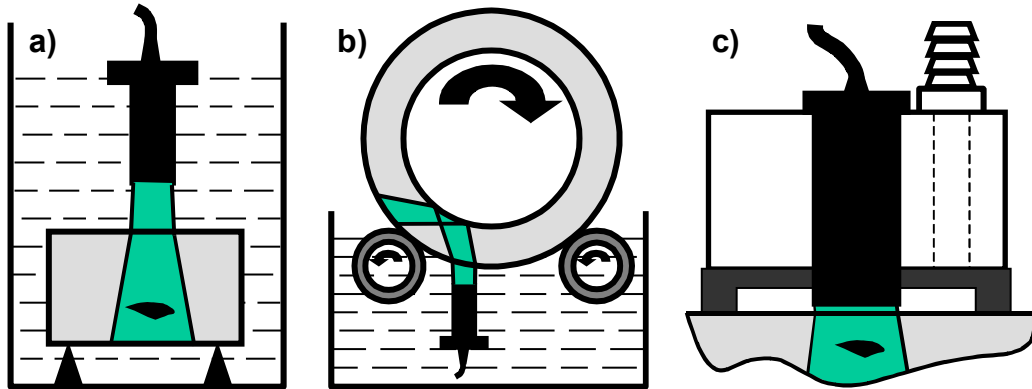


Figure 1: Ultrasonic coupling techniques, a) immersion testing, b) partial immersion, c) gap coupling.

Guided water jet coupling offers a higher near-field resolution and better protection of the probes. Again, wear-resistant skids or rollers can be used to guide the probe holder along the specimen. Standard immersion type probes are used and a fairly long water column (30 – 50 mm) between probe and specimen guides the ultrasound. With this technique, compact multi-probe carriers have been invented by *Karl Deutsch* more than 25 years ago for the inspection of gas containers. Other common applications are bar testing and billet testing.

Free water jet coupling is entirely wear-less. This method is especially suitable for the inspection of complex profiles such as rails. Initially only applicable for through-transmission testing, this technique has now been modified for pulse-echo testing. Between probe and specimen, a free water column of approx. 20 mm is generated. The probe holders are fairly complicated. Producing a water column which is bubble-free for undisturbed guidance of the ultrasound is a difficult task. Several rail inspection systems have now successfully been installed using this method.

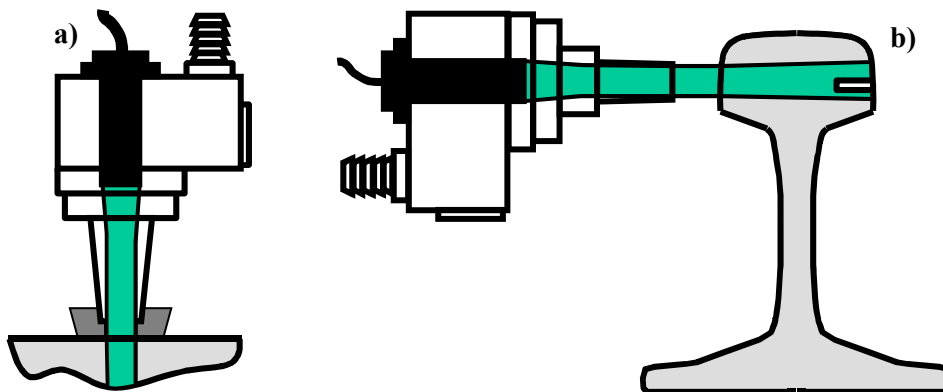


Figure 2: Ultrasonic coupling techniques, a) guided water jet, b) free water jet.

Several ways have been explored to reduce the mechanical extent which is necessary for the coupling. Wheel probes, electromagnetic transducers (EMAT) and laser ultrasound are such approaches. Each approach has shown advantages and disadvantages. It remains to be said, that immersion testing, gap coupling and water jet coupling dominate the industrial use.

3 Inspection of seamless tubes and gas containers

The highest-possible through-put is achieved, if mechanical rotation is avoided. A fairly new concept uses a multitude of stationary probes where the entire circumference of the pipes is surrounded by the probes. The inspection is carried out in immersion, meaning that the probes are mounted in water filled test chambers. Specially designed closing mechanisms open and close the test chambers according to the position of the specimens. For the inspection of round profiles (tubes & bars) curved probes have been developed. 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 inspection. Also, the detection of short flaws is a strong point of a stationary system. In order to keep the number of probes reasonable, the maximum tube diameter for this system is currently limited to 170 mm.

Large tubes with diameters up to 610 mm can be inspected in partial immersion. 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.

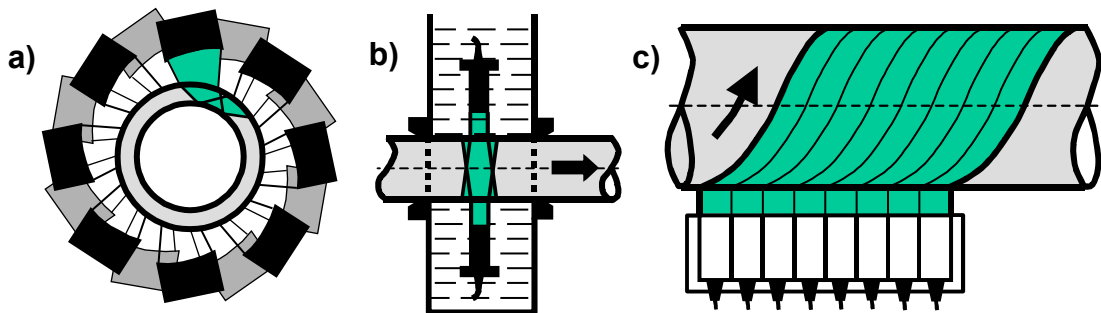


Figure 3: Tube inspection, a)+b) high-speed tube inspection with curved stationary probes, c) rotational inspection of large diameter tubes in partial immersion and with multi-probe batteries.

The third option for tube inspection covered in this paper is especially suitable for an off-line inspection. In principle, all diameters can be inspected with this set-up. 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.

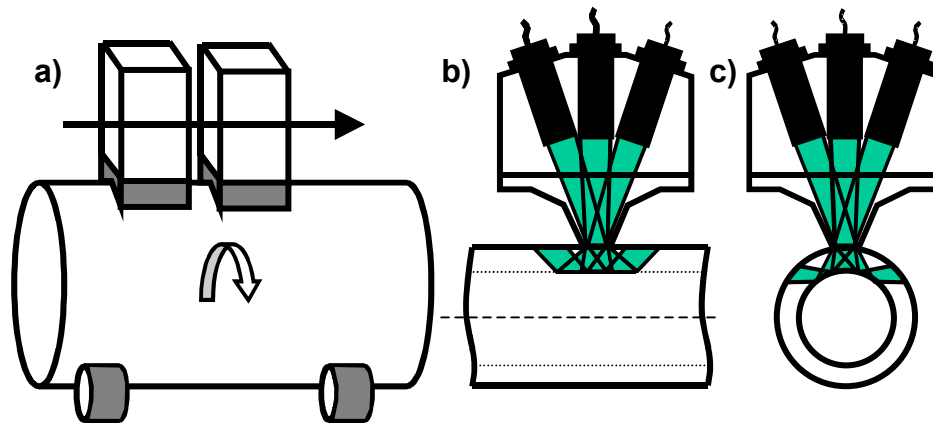


Figure 4: Testing traverse for tubes and gas containers with multi-probe carriers, a) rotating specimen and linearly moved probe holders, b) detection of transverse flaws and wall thickness measurement, c) detection of longitudinal flaws and wall thickness measurement.

For the inspection of gas containers, similar testing methods can be used for the cylindrical portion of the container. Usually, a traverse-type system is used where the rotating container is inspected by linearly moved probe holders. Multi-probe holders allow for the detection of all flaw types. The bottle neck or bottom is usually inspected manually. The test result for the cylindrical portion is then linked to the manual inspection result and a joint protocol is produced for each container.

4 Inspection of bars, billets and strips

In earlier years, the focus for the inspection of such profiles was on the detection of core defects. Few probes which cover the core-zone of the specimen were considered sufficient. In most cases, gap coupling was used. After the production process shifted to continuous casting and since the requirements on the materials steadily grow, a higher coverage of the profile is necessary.

The inspection of bars and billets is currently performed using guided water jet coupling. High through-put rates are achieved by having a multitude of stationary probes surrounding the profile. Dependent on the geometry, normal incidence or oblique incidence is used for achieving high coverage of the profile. Testing speeds of 2 m/s are standard and high pulse repetition rates lead to full coverage in the axial direction. Usually, one ultrasonic pulse is transmitted every 1-2 mm.

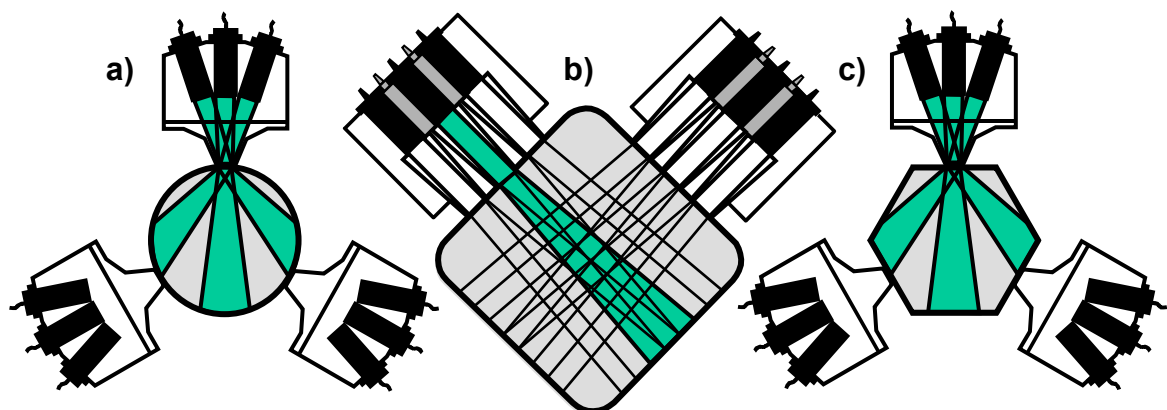


Figure 5: Ultrasonic inspection of bars and billets, a) inspection of round bars with 9 probes, b) inspection of quadratic billets with 10 probes, c) inspection of hexagonal bars with 9 probes.

Round billets or aluminium bars with large diameters are usually inspected with helical test traces. In principle, the set-ups are similar to the testing traverse for tube inspection. The through-put rate determines the number of probes.

For strip inspection, dual-element probes with gap coupling are commonly used. Since the sheet thickness is usually small, dual-element probes have to be used. Special probe geometries have been developed in order to

produce wide test traces. The wider the test trace, the smaller is the number of probes. On the other hand, large probe faces are less sensitive to small defects and a compromise has to be found.

5 Rail inspection

For early rail inspection most attention was paid to the inspection of the rail head. Only the fairly flat surfaces could be inspected with gap coupling techniques and therefore the rail head and the rail flange was tested. Again, stricter safety standards and the invention of high-speed trains has led to a more sophisticated way to inspect rails.

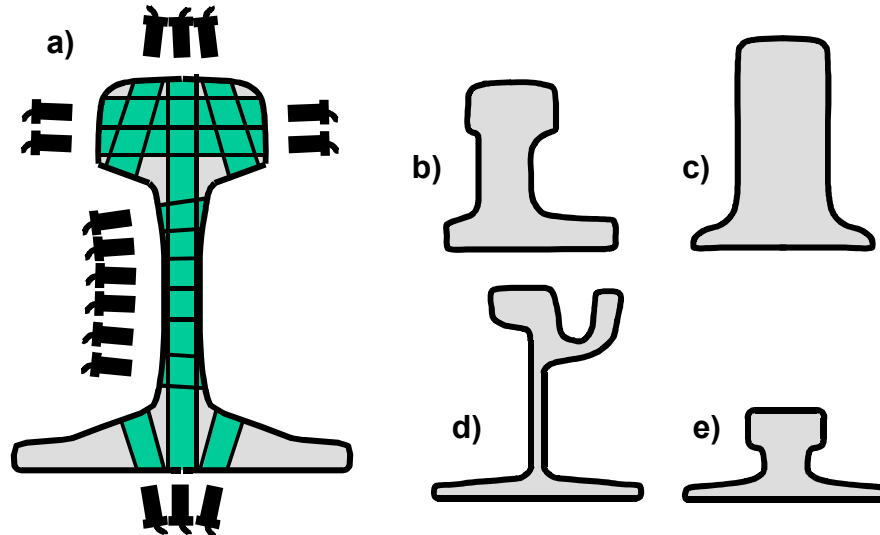


Figure 6: Ultrasonic rail inspection with free water jet coupling, a) coverage with 16 probes for standard rail profile, b-e) various rail profiles which can be tested with the same system set-up.

Sixteen probes using free water jet coupling have been found sufficient to satisfy current test standards. Again, a high testing speed of 2 m/s is standard and three degrees of freedom for each probe carrier allow for a convenient adjustment of the probe carriers. The probe height, the distance from the rail and the incidence angle have to be adjustable in order to inspect various rail profiles with the same testing system. Several steps of automation can be pursued: from manual adjustment of the probes to fully motor-controlled positioning devices. These features naturally influence the change-over times from one profile to the other.

The standard set-up uses 7 probes for the rail head, 6 probes for the flange and 3 probes for the rail foot, but other configurations are also feasible.

6 Weld inspection

For weld inspection, the cross-section to be tested is reduced to the weld itself and to the heat-affected zones besides the weld. Usually, already the welding process is automated in order to make an automated testing system worthwhile. Most applications involve tube inspection where two types of weld have to be considered.

Smaller diameter tubes are mostly electrically welded (ERW). The simplest way to inspect ERW-welds is carried out with an oscillating wall-thickness measurement (deburring check). Of course, flaws inside the weld are also found with such measurement. One probe holder with a normal probe oscillates across the weld while the tube is linearly moved. One probe can not lead to a full coverage of the weld. The second problem is the irregular shape of front surface and back wall of the weld. If the deviations are too strong, a backwall echo is not received and a wall-thickness measurement is not possible.

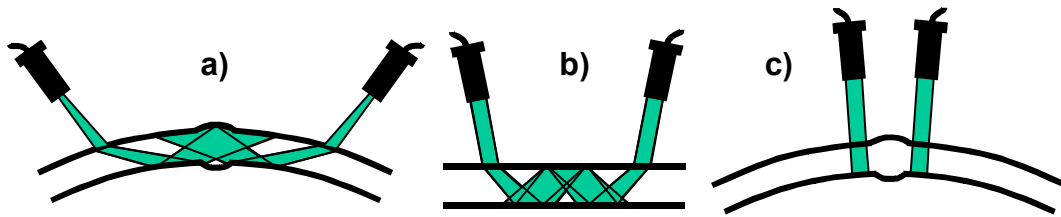


Figure 7: Weld inspection on tubes, a) longitudinal flaw detection (here external flaws), b) transverse flaw detection, c) lamination testing and wall thickness measurement besides the weld.

In most cases, several probe pairs are used for the detection of all flaw types inside the weld. Longitudinal flaws inside the weld are found by probes located perpendicular to the weld. Dependent on the wall thickness, more than one probe pair might be necessary.

The optimal probe orientation for the detection of transverse defects is given, if the probes are located directly on the weld. Systems have been developed where free water jet coupling allows for such an arrangement. Two probes are tilted with respect to the tube axis and are facing each other. Conventional systems use a compromise and arrange the transverse probes under an angle of 45° with respect to the weld (K-arrangement and X-arrangement, usually with gap coupling).

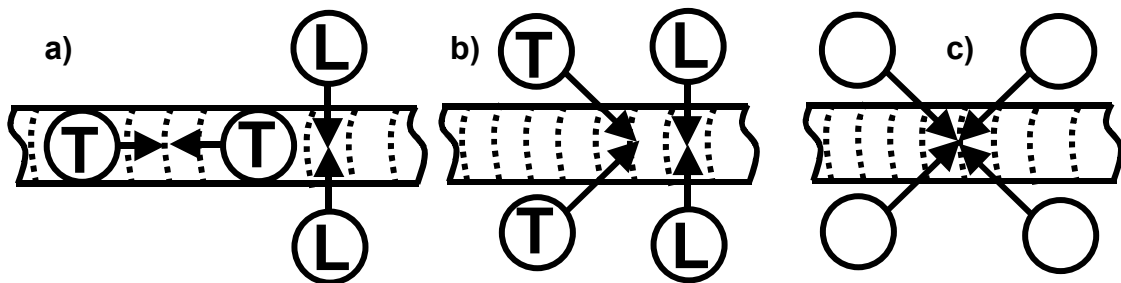


Figure 8: Possible probe configurations, L = probes for longitudinal flaw detection, T = probes for transverse flaw detection, a) configuration with free water jet coupling with T-probes directly on weld, b) K-arrangement of probes, c) X-arrangement of probes.

Probe pairs (e.g. one longitudinal probe on each side of the weld) are always used in order to find defects with strong directional characteristics. The second reason for always using probe pairs is the use of the V-transmission signal between two probes for a coupling and system check. If the transmission signal is missing or weakened, either the coupling, the probe or the entire system is not working correctly. Thus, the transmission signal is constantly supervised and ensures the stable operation of the system.

Large-diameter tubes are usually submerged-arc-welded (SAW). Spiral welds and longitudinal welds are possible which is dependent on wall thickness, diameter and later use of the tube. A large wall thickness mostly requires a longitudinal weld which is often inspected off-line. Since those tubes are very heavy, the through-put rate is low and an off-line inspection is sufficient. Often, spiral-welded tubes are produced fairly quickly and therefore, an on-line inspection directly after the welding station is often encountered.

The test procedure is rather similar to the testing of ERW-tubes: Longitudinal and transverse flaws have to be detected. Laminations next to the weld have to be found and sometimes wall thickness measurements are required. Gap coupling techniques are often used, but new systems have been presented which use free water jets. Again, the advantages are less wear of the probe holders and improved positioning of the probes with respect to the weld.

7 Ultrasonic electronics

The evaluation of the ultrasonic signals is carried out with multi-channel electronics. The electronics can be programmed according to all previously mentioned testing tasks. In general, a multitude of channels is necessary and each channel can be individually configured.

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 distance-amplitude-

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correction (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.

As a supplement to the electronics, a data management system is provided. The test data is processed according to the customers needs using a IBM-compatible PC. Test protocols are generated, the test parameters are stored for quick retrieval and therefore for short change-over times. The operation system Windows NT allows for a convenient operation of the entire testing system.

An extra electronic module 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 specimen is subdivided in so-called test intervals where the spatial resolution can be chosen. An on-line display of all signal amplitudes with respect to the specimen position is shown on the PC-screen. Exceeding of the pre-set amplitude thresholds is clearly visible and helps the operating personnel to supervise the current inspection. The system operator 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 available. A statistical evaluation contains all collected data, e.g. for an entire batch or a working shift.

8 Summary

This article contains a brief overview on automated ultrasonic inspection of various specimens. The most common applications are discussed. Many other system configurations and testing tasks have been automated. Most of them are based on the principles discussed in the paragraph on coupling techniques. The automated inspection is quite different from the manual inspection: the test traces are predefined and flaw echoes can not be maximised by small movements of the probe. On the other hand, the subjective influence of the operator is ruled out, leading to reliable test results. Also, high quantities of specimen are more reliably tested with an automated test procedure.

9 References

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