Requirements and possibilities to guarantee the working order of automated ultrasonic imaging systems

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Abstract

In order to guarantee reliable results of the imaging ultrasound test, it is necessary to check the test system itself regularly, partly before and after each test. Possible errors in the test system arise, e.g. by earing the probes, wear of the mechanics, misalignment or defects of the UT system. A common method is the examination of a defined reference specimen and the comparison of the result with previous scans by the examiner. By subtracting the master C-scan and displaying the result, differences can be assessed more easily, thus saving time and improving reliability. Partially, the auditor can also be dispensed with by means of automatic analysis. Corresponding tools are available for our testing set-ups and will be presented in the paper.

It is important for the meaningfulness of this test method that the test parameters, the amplitude dynamic range and the structures of the reference measurement to be mapped correspond to those of the subsequent component test. This requirement can be easily achieved in the examination of serial parts, but not in the case of various tests, e.g. in the laboratory.

Since the imaging properties are checked during the reference test but not all possible system functions are tested, a periodic calibration of the UT system is necessary. The characteristics of the test system are systematically recorded, documented and checked for compliance with limit values. For our test systems, we also offer this as an on-site service.

1. Introduction

For ultrasonic flaw detection with center frequencies up to 15 MHz applicable standards exist (1, 2). However, there are no standardized rules for high frequency systems and least of all for air coupled imaging ultrasonic systems. For imaging systems only a subset of the rules can be used. Furthermore, due to differing requirements of the air coupled technique a simple transference is not approvable. Because of that we had to develop and optimize our own calibration methods.

In this paper possible influences which can disturb an automated ultrasonic inspection are recapitulated. Immersion technique as well as air coupled systems are considered. Possible reasons, methods for detection and prevention are discussed.
2. Influences on measurement precision

2.1 Definition of relevant and irrelevant influences

There are numerous influences which can disturb an automated ultrasonic inspection and can lead to unusable results. A differentiation can be performed with regard to their prevention possibilities by the investigator during operation or in service by the system manufacturer. In this paper the term relevant influences is used for such effects.

Apart from that some effects exist which cannot be compensated easily or entirely. They have to be handled suitable. Here, the term irrelevant influences is used.

2.2 Discussion of relevant influences

2.2.1 Manipulator

A mechanical axis of a high resolution ultrasonic imaging system must fulfill high quality standards. Otherwise position deviations or slippage effects are possible. Reasons for slippage effects can be a too high scanning speed, mechanical resonances, gear margins, elastic deformations or specimen vibrations during scanning. The resulting disturbance concerns high frequency imaging investigations with a high lateral resolution. It can be proved on such systems with a simple and cheap reference specimen: a coin. Fig. 1 shows the C-scan result of a 2 Euro coin, investigated in pulse-echo technique with a 50 MHz transducer and our USPC 3060 UHF scanning system. Here, a slippage was generated artificially to demonstrate this effect. The position deviations are clearly identifiable in the zoomed picture although they are below 50 µm. Fig. 1.C shows same result without slippage.

![Coin C-scan with and without slippage](image)

Figure 1. A) C-scan of a 2 Euro coin and zoomed area B) with slippage and C) without slippage.

2.2.2 Ultrasonic Hardware

Loose contacts in the ultrasonic hardware or in the signal cables can be identified easily due to a missing receiver signal. The problem can affect only small areas of the scanning field or even single positions (pixels) which is hard to evaluate. Corroded contacts can cause complex disturbances which may be visible only on small frequency sections. Therefore, a reliable system calibration is necessary which considers the entire working spectrum.
2.2.3 Probes and Coupling

The proper ultrasonic probe and the inspection frequency have significant influence on inspection results. The resulting wavelength must be less than a sought defect. On the other hand, damping effects rise with the frequency which limits the applicable bandwidth additionally. In practice, a selected frequency band can be suitable.

In the case of focused probes, the distance between sensor and the specimen surface must be adapted to the relevant specimen section plane. Therefore, an effective focus distance must be considered. Further relevant parameters are the sound beam width and the focus zone which is characterized by the highest sensitivity. If the specimen thickness is larger than the focus zone, not the entire specimen thickness can be investigated which enables undetected defects.

The probe angle can also be a critical value, not only in transmission technique. This can be controlled by adjusting of the probe orientation for example to the highest signal amplitude. If sensor arrays are used, every sensor must adhere the same sensitivity and must not show direction or frequency dependencies in order to guarantee consistent imaging results. This can be achieved by an adapted calibration procedure.

The air coupling itself usually do not raise special problems. Only in case of airflows between probes and the specimen an investigation can be disturbed and a compensation strategy may be necessary.

In the case of immersion technique any air bubbles must be avoided. Instead of fresh tap water only outgazed water should be used. Residual air bubbles must be removed from the specimen and the probe surface.

Some specimens like sandwich structures are not allowed to be submerged. Here, a local water coupling can be used like our LIUS adapter. A water management system generates a constant water coupling between immersion probe and the specimen surface without disturbing the ultrasonic transmission. With this technique even 65 MHz investigations are possible (3).
2.3 Discussion of irrelevant influences

2.3.1 Weather

The environmental conditions (weather) are sorted to the irrelevant influences. A precise control of temperature, air pressure and humidity within inspection area is expensive and not practicable. As long as no disturbing dust particles have to be filtered, a special climate cabinet is typically not necessary. One influence on an ultrasonic inspection is caused by the air pressure in the form of a viable sound velocity which does not change fast. This can be compensated easily by adjusting the focus distance. An influence on the amplitude usually does not exceed ±2 dB. This can be compensated by an automated gain adjustment on behalf of a simple reference specimen which does not disturb the investigation results if no absolute thresholds are used.

2.3.2 Equipment Tolerances

Temperature-dependencies or influences of electromagnetic perturbations to the equipment are prevented by the manufacturer during the system layout. Therefore, a working temperature range is specified. This includes the mechanic components, electric hardware as well as the ultrasonic probes. Aging-caused changes of this must be identified within regular operation tests and calibration procedures.

3. Methods to guarantee of the inspection reliability

To guarantee inspection reliability which enables a POD of nearly 100% is a hard challenge. Because of that different techniques are used complementary.

3.1 Automatic system check

In order to detect problems of a scanning system automatic checks can be implemented and executed on every system start. This includes the energy chain, hardware of the control computer and signal circuits. The system manufacturer has to guarantee that no automatic checks, software or operation system updates can interrupt a running ultrasonic investigation.

3.2 Regular scanning of a reference specimen

An established method to ensure the defect detection reliability is the regular scanning of a reference specimen. The reference specimen must be comparable to the inspection specimen with regard to design, used materials and constitution. Artificial defects placed in the reference specimen must fulfill all requirements to represent the full bandwidth of defects which must be detected in the inspection specimen. Typically, flat bottom holes with different diameter and depth are used. A reference part and the test specimen should be investigated with the same settings.

An air coupled inspection result of a unidirectional CFRP component with 5.3 mm thickness is shown in Fig. 3. Here, flat bottom holes with a depth of 2.6 mm and different diameters are introduced. The inspection was performed with our AirTech 300-R/T
probes for 300 kHz. Fig. 3.A shows the C-Scan with descriptions of the hole diameters. In Fig. 3.B the amplitude dynamics through the hole positions at y = 110 mm is printed. It shows the dropout of the signal from at least -6 dB in the undamaged area to below -14 dB within hole positions. This exceeds the required amplitude difference of 6 dB for a damage detection. The amplitude at the 2 mm hole shows a dropout of only 2 dB, which permits only to adumbrate a defect but is not enough to prove it. The example proves the detectability of 3 mm defects with the air coupled technique.

Figure 3. A) Example C-scan of an air-coupled investigation of a reference specimen, and B) its amplitude dynamics at Y = 110 mm.

3.3 Tools for comparison of results

If the same reference part is scanned regularly as described in section 3.2, its investigation results have to be compared by the operator. Such a manually conducted check is time-consuming and error-prone. Differences between the C-scans can be compared easier by subtracting the reference scan form the actual result like shown in Fig. 4. This reference specimen in permanently mounted in our FlatScan systems and can be used for a regular reliability check. Further client-specific reference parts can be mounted too. If the reference part is not permanently mounted in the scanner system, automated corrections of position (translation and rotation) may be necessary. There are options for our software Hillgus and Oculus to perform the steps automatically.
3.4 Regular calibration of the equipment

A regular calibration of the inspection equipment is necessary to identify all remaining problems of the system. It prevents also aging-caused degradations to influence any inspection results.

For the calibration of air coupled systems special requirements must be considered. Our ultrasonic systems can be calibrated even on site by the Hillgus test software, the HillScan Calibration 300 hardware for immersion technique and AirTech Calibration 4000 hardware (see Fig. 5) for air coupled systems. The calibration procedure involves the ADC-board, burst-pulser, receiver, preamplifiers and probes.

Although a yearly calibration is prescribed by the relevant norms (1, 4), we recommend a two-year interval for our systems. This reduces calibration costs to 50% without an inferior system reliability.
4. Conclusions

The paper contains an overview of most important influences which may disturb an ultrasonic imaging investigation and lead to falsified testing results. The influences are differentiated into relevant and irrelevant. Possibilities for their detection and prevention were presented. Finally, methods to guarantee of the inspection reliability are discussed.

To ensure the inspection reliability of an ultrasonic imaging system, regular system checks and the scanning of a reference specimen with validation of its results are necessary. Furthermore, a valid calibration of the equipment cannot be avoided.

References

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