MULTIPLE NDT METHODS IN THE AUTOMOTIVE INDUSTRY

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Abstract: The automotive industry must meet the requirements for increased safety (product liability), stricter regulations regarding environmental protection, as well as the demands of car drivers for more luxury features. Costly recall actions, ever increasing demands on the quality management and the changing legal framework with a simultaneously harsher competition force the industry towards a more economic direction. Improved accessories for vehicles lead to increased weight. Higher weight also means higher gasoline consumption. This is only one of the reasons for today's "lightweight design" of new vehicles. Whereas steel was with more than 80 percent the most important material for the automotive industry in the past, other materials such as plastics, magnesium and aluminum will become more important in the future. The use of several materials will inevitably lead to new joining techniques since the traditional joining techniques, e.g. spot welding for body constructions, can only be partly used. A combination of methods will replace a single dominant method in the future. Due to the changed conditions with regard to material and joining technique, quality assurance must likewise adapt itself to the changes in production conditions. New test techniques are not only meant to determine the current quality of a bonded joint but also more and more to positively influence the whole process by corresponding measured variables. The industry will have to invest in safety and quality in the future as well because the conditions related to product liability will continue to cause recall actions and other cost-intensive measures. Advanced processes will be in demand, measured by (NDT) variables in the field of quality management.

The lecture sheds light on feasible solutions in the automotive industry (e.g. quality inspection of joining techniques in car body framework and of casted components) using various methods (ultrasonic, x-ray etc.) and the resulting benefits for the users.

References: W. Roye "Nondestructive Inspection Methods in the automotive industry", 8th ECNDT Conference, Barcelona (Spain), June 17-21, 2002

Spot welds

The computer aided spot weld inspection, see Figure 1, has achieved a high state of the art and is applied by almost all car manufacturers. Here, the principle is briefly discussed, see Figure 1:

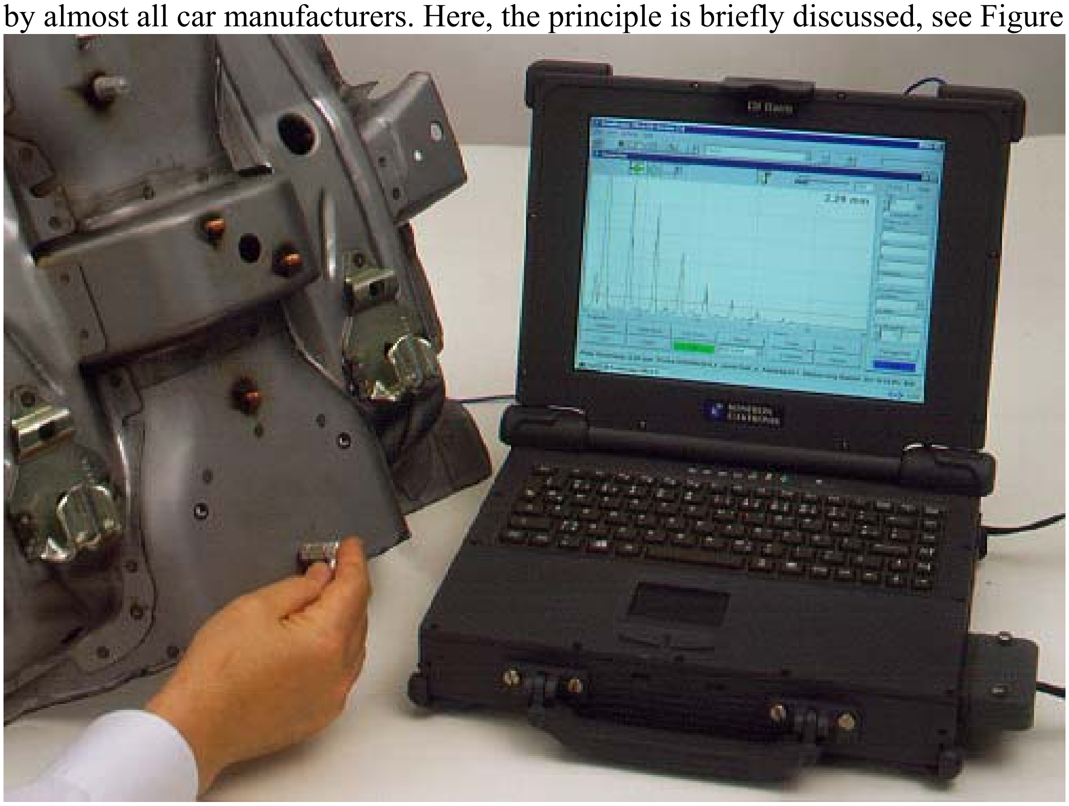

Figure 1: Spot Weld Inspection

In the case of a good spot weld [1] we obtain an echo sequence as shown. Due to the coarse grained material and the related sound attenuation the echo sequence decays quickly.
If the spot is too small [2], the echo sequence contains intermediate echoes due to the fact that the sound field diameter is larger than the spot diameter.

A stick joint [3] is transparent for the sound but the lower sound attenuation leads to a longer echo sequence.

Finally, if there is no bonding [4], one obtains an echo sequence from the first plate only.

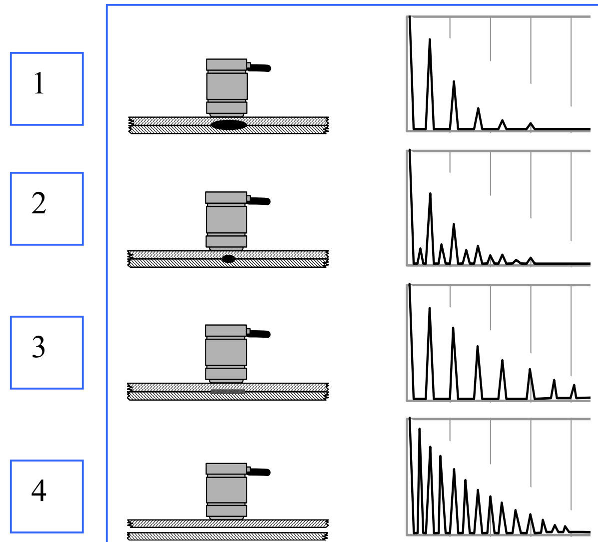

Figure 2: The principle of spot weld inspection

Laser seam welds

Overlapped laser seam welds, e.g. in the roof channel of a car body, can be inspected by means of the ultrasonic transmission technique, as shown in figure 3: The emitter probe E generates a guided wave through the plate and the laser weld L. In case of a good weld performance, the ultrasonic signal is received by the receiver probe R.

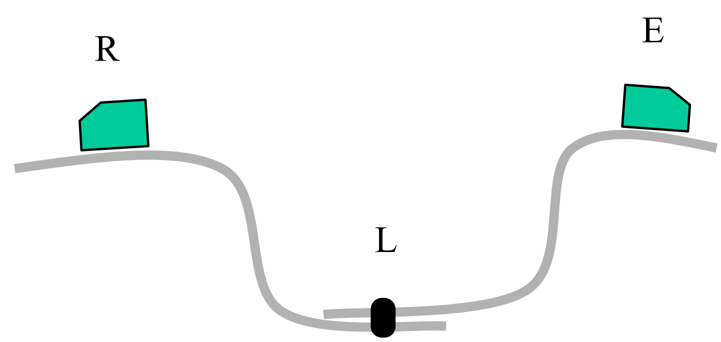

Figure 3: Inspection Scheme

First prototypes contained standard angle-beam probes with a flowing water coupling device. But as any fluid for coupling purposes is not permitted because of the later painting process, GE Inspection Technologies developed a system with roller probes which enable dry coupling. The system is shown in Figure 4. It contains

- the roller probes,
- a probe holder with springs, which enable the geometric adaptation to the changing surface of the object construction,
- a guide system which ensures the correct position of the probes along the whole length of the laser weld seam
- and finally a position encoder.

The inspection is computer aided. The computer receives the sound amplitude values from the ultrasonic system and the corresponding position data from the position encoder, and a dedicated software thus allows an inspection procedure including documentation.
This type of ultrasonic transmission technique will not be able to detect extremely small defects in the weld, however, practical application tests in several automobile companies demonstrate, that all relevant bad through welding defects can be detected reproducibly.

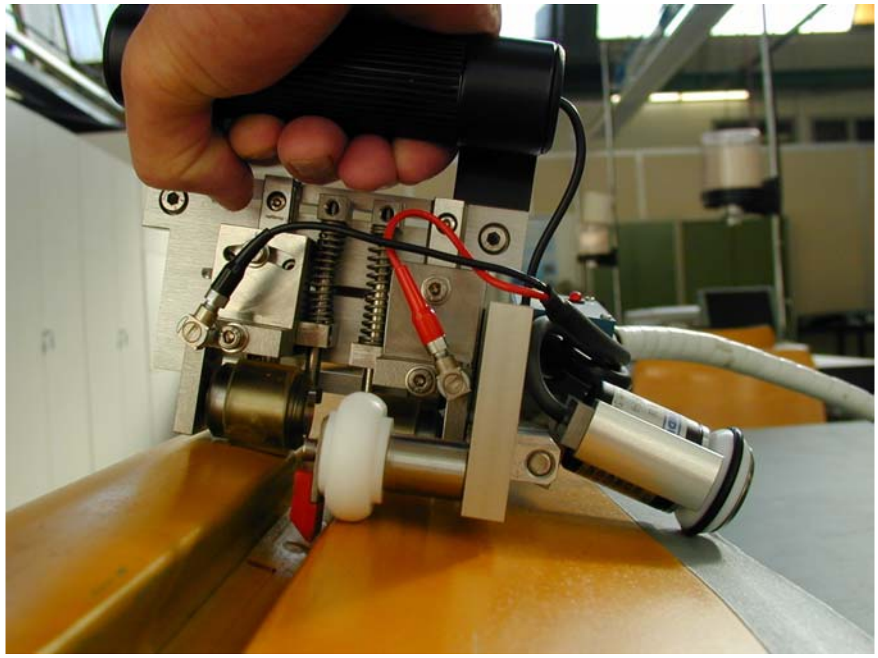

Figure 4: The roller probe setup for the laser weld inspection

Gas shielded welding

Different components of a car body are joined by MIG (metal inert gas) or MAG (metal active gas) welds. In most cases the geometry does not allow any type of ultrasonic impulse echo method. Therefore for this kind of weld, GE Inspection Technologies proposes the ultrasonic transmission technique, as shown in Figure 5:

Also for this application a special probe system was developed, see Figure 6:

The emitter probe contains three transducers, which generate sound beams into three different directions. The sound waves propagate through the plates and the weld as a guided waves and can be received on the other side by means of the second probe, e.g. K2MNE. In order to simplify the inspection procedure, the emitter probe is equipped with four magnetic feet for self fixation to the metal object.
Gas shield welding is applied e.g. for the joints of door hinges, the bows of the seat fixture and several other components. In all cases a good weld is indicated by a high ultrasonic amplitude and a bad throughwelding by a lower signal, Figure 7.

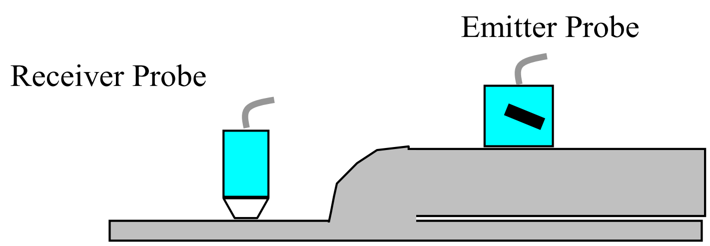

Figure 5: Inspection layout for MIG/MAG welds

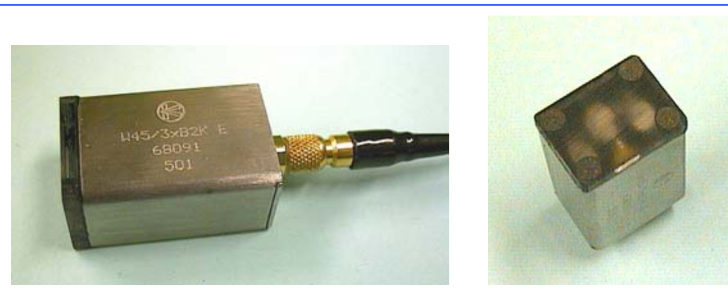

Figure 6:Special probe W45/3xB2K

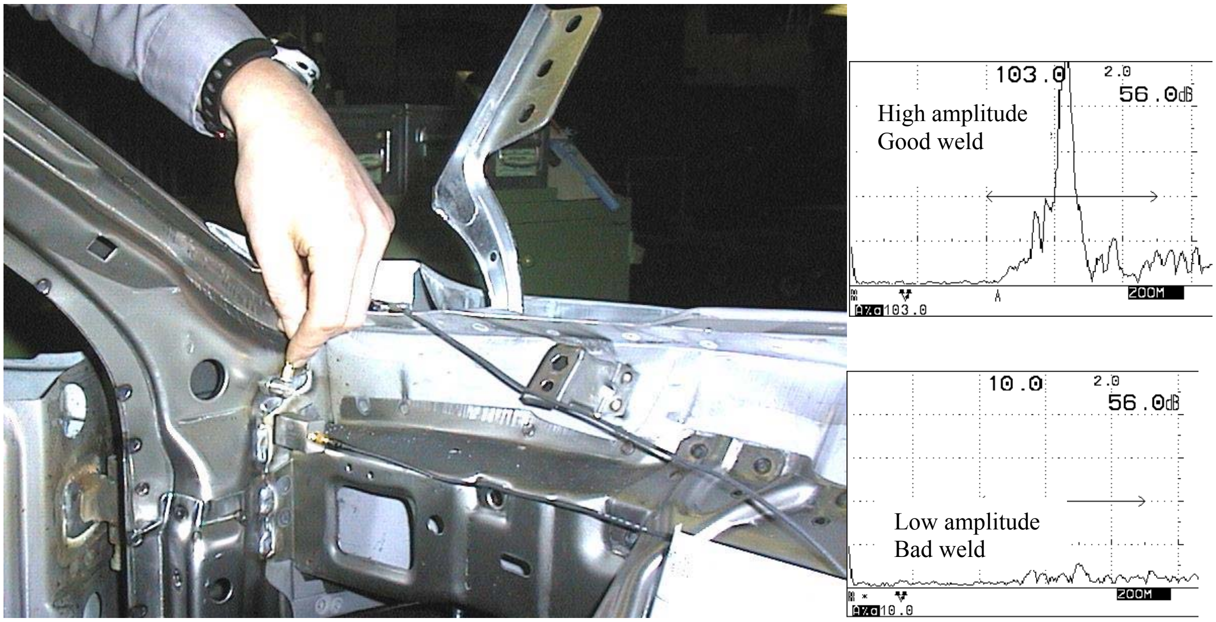

Figure 7: Ultrasonic inspection of MAG welds

Adhesive Joints

More and more adhesive joints are applied in the automobile and aircraft industries. This concerns the joints of metal plates as well as combinations of steel, polymeric materials and glass.

The example in Figure 8, two adhesively bonded steel plates with a thickness of 1 mm, were inspected.

Principally there are two possibilities:

If a relatively high sound frequency is used, e.g. 20 MHz, then we obtain a good echo sequence out of the first plate, which is highly attenuated by the adhesive if the adhesion is good, see Figure 9. In case of a bad adhesion or missing adhesive, the sound damping is non-existent, which leads to a long echo sequence. However, a disadvantage of this method is, that only the first interface between plate and adhesive can be inspected, because the high frequency sound does not interact with the adhesive material.

If we apply a low frequency, e.g. 2 MHz, then an interaction with the adhesive can be observed, however, it is not possible to obtain resolved echoes in the time domain. For this case the spectral analysis in the frequency domain is proposed.

As an example Figures 10 and 11 each present the A-Scans of the interfering signals of the plate and the adhesive. A gate is set to the interference from the adhesive. The time range of the gate is presented once more in the left upper side and the corresponding frequency spectrum is presented at the right side. The

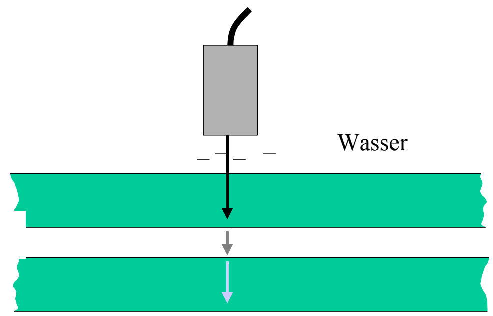

Figure 8: Inspection of adhesive joints

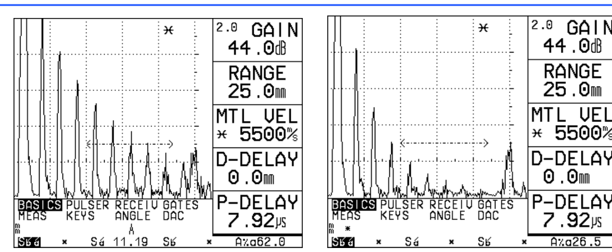

Figure 9: Echos of a 20MHz probe

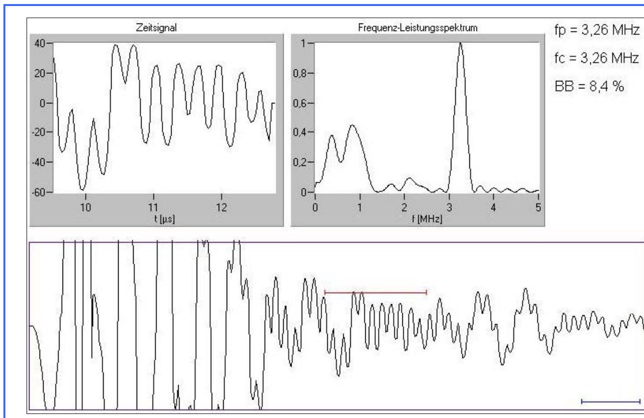

Figure 10: Good adhesion

printed values mean: fp – Peak frequency, fc – Center frequency and BB – Bandwidth.
It can be clearly seen, that different gluing qualities lead to different interference patterns in the time domain which can easily be evaluated in the frequency spectrum.

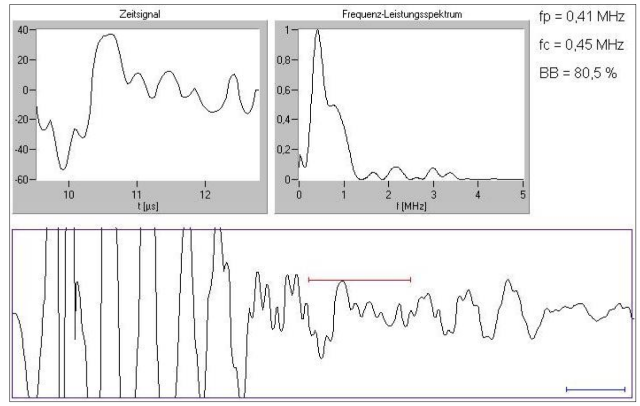

Figure11: Bad adhesion

Laser welds of airbag gas generators
An airbag gas generator is shown in figure 12. It contains several laser welds.
The partial design of the object with weld is presented in Figure 13. The task is to measure the depth of the weld and to detect defects, e.g. pores, in the welded zone. For this purpose it is recommended to apply the ultrasonic immersion technique in combination with the point focussed probe H10MP15 (f =10 MHz, focus depth = 15 mm in water). With a radial insonification and by means of an object rotation and probe shifting a C-Scan-Image (Helical Scan) is obtained, as presented in Figure 14.
Here, the echo amplitude is plotted to the rotation angle (0 to 360 degrees) and the probe shift (0 to 17 mm). The amplitude is colour coded: red represents a high amplitude of the backwall of the first plate or of defects in the weld and green presents a low amplitude or missing signal. This allows the detection and localisation of defects as well as the evaluation and determination of the weld depth, as demonstrated in the magnified C-Scan part, Figure 15.

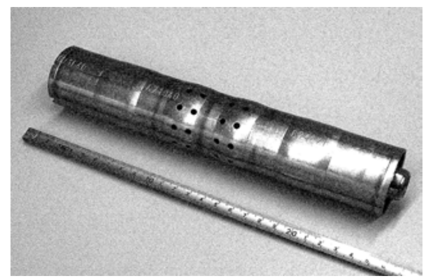
Figure 12: Airbag gas generator

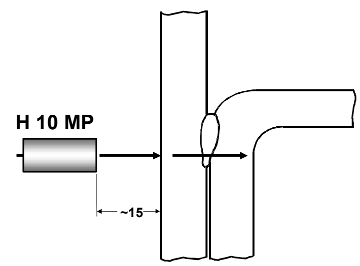

Figure 13: Partial section with Laser

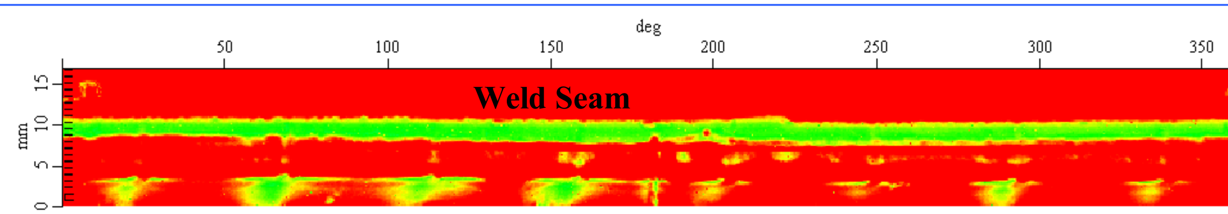

Figure 14: Circumferential C-Scan

The accessories used for this application were:

- ultrasonic instrument: Krautkramer USD15,
- probe: H10MP15,
- an immersion tank with a shift axis and a rotation device and
- Software: UltraMAP for motor control, data acquisition and generation of C-Scan images.

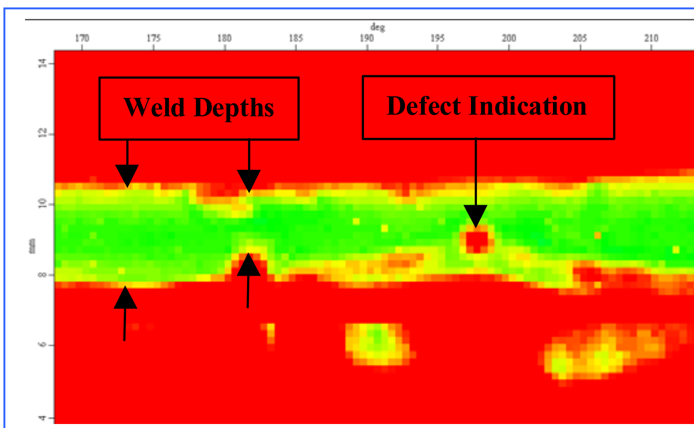

Figure 15: Magnified Part of the C-Scan

Bonding test between the cylinder liners and the casing of motor units

The considered motorblock unit is made of cast aluminum and contains cylinder liners made of gray cast iron with a wall thickness of 4 mm. The inside diameter is 80 mm.
The task is to inspect the bonding between the cast iron liner and the aluminium casting.
As shown in Figure 16, the wall of the liner is scanned by vertical beaming using the immersion probe H5K and a 45^0 deflection mirror. The quality of bonding can be read from the amplitude of the backwall echo: A small echo indicates "good bonding" and a high signal the "bad bonding".
In order to generate a C-scan, the total liner surface area is helically scanned from inside. To achieve this, the probe is shifted vertically, and the deflection mirror is rotated around its axis.
Figure 17 shows a motor unit and the probe holder with the deflection mirror. This system permits a helical scan of the entire liner surface area.

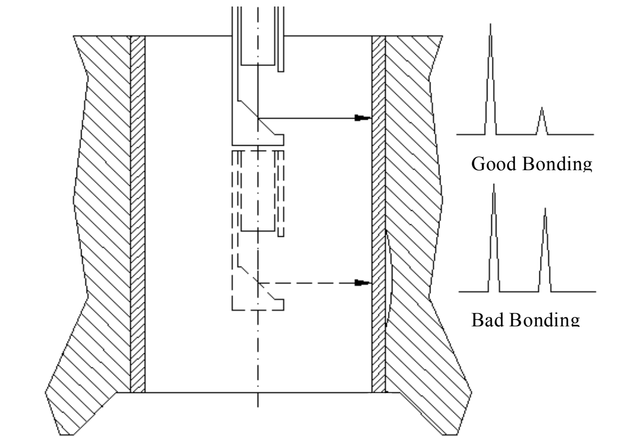

Figure 16: Al-motor block with cast iron liner

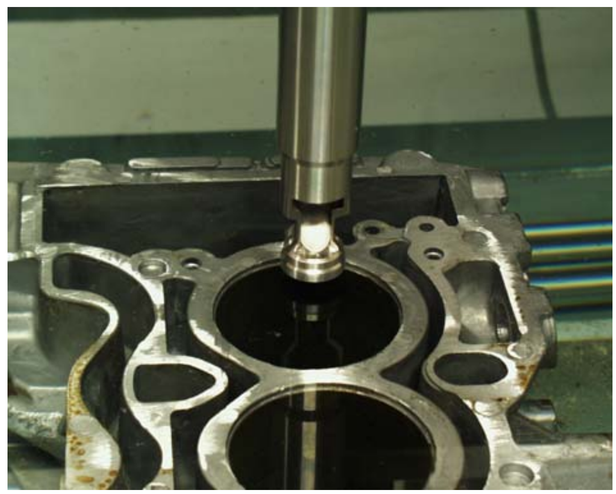
Figure 17: The motor block and the ultrasonic probe with deflection mirror

Figure 18 presents typical C-scans as a result of the bonding test. The high amplitudes (bright) to be seen there indicate areas of bad bonding, i.e. the lack of fusion.

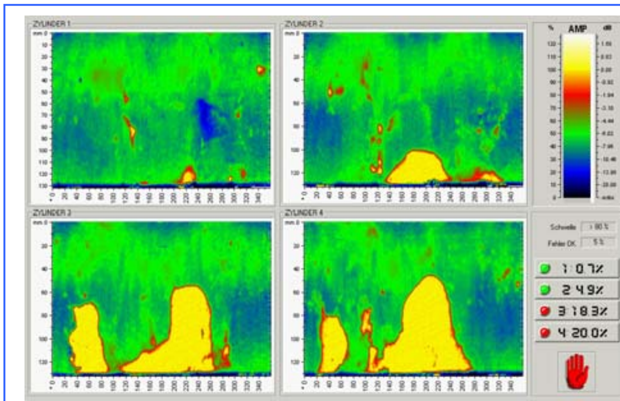
Figure 18: C-scan-plots of 4 cylinders

The accessories for this application were:

- Instrument: Krautkramer USD15
- Probe: H5K
- Scanning system
- Software: K-Scan

Wall thickness measurement on cast camshafts

Typical casting defects are “core mismatches”.
The consequence of such defects in camshafts are failures because of extreme dynamic loads due to reduced wall thicknesses.

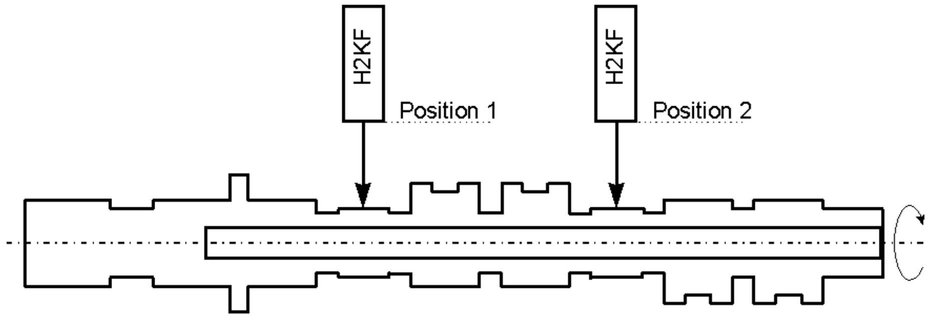

Figure 19: Ultrasonic measurement of thicknesses on a camshaft

The recommended solution is to measure the wall thickness on the bearing points. The simple, annular geometry of these points enable the shaft to be tested in the casted state. Further processing actions on any defective parts can thus be excluded.

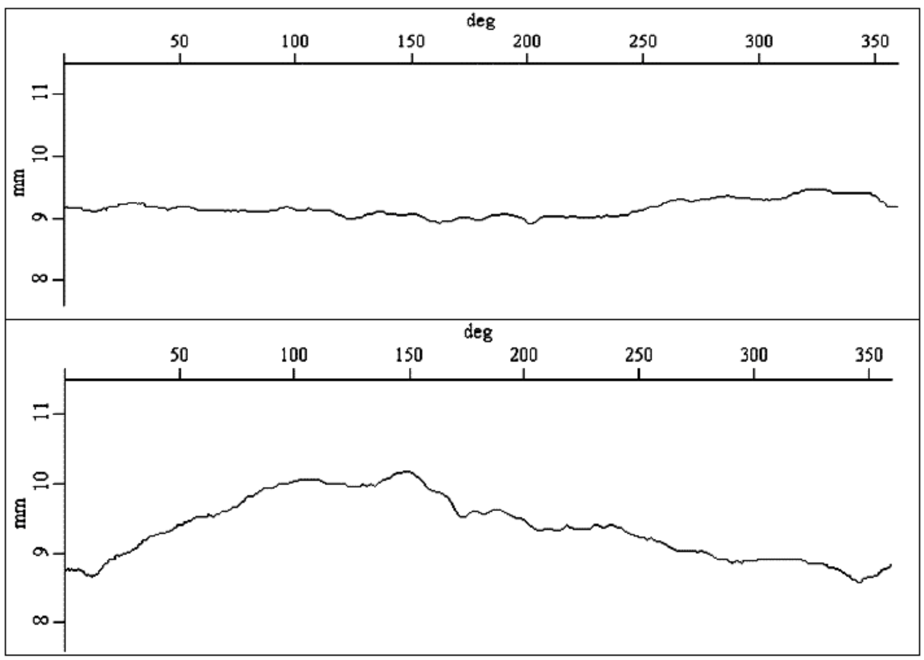

Figure 20: Lineplots of circumferential thickness measurement

This method makes it possible to recognise the core mismatch by a reduced wall thickness and excessive wall thickness on the opposite side (180°). The waterflow technique, using a so-called squirter or bubbler probe, is applied according to the arrangement shown in the sketch, Figure 19. This ensures a constant coupling in the area of the bearings around the entire circumference during camshaft rotation. Figure 20 presents two lineplots (thickness to rotation angle). The upper plot represents a uniform wall thickness with a $\Delta d < 0.6$ mm and the lower plot shows a varying thickness with a $\Delta d > 2.5$ mm.

Hardness test on the running surface of a camshaft

In order to attain adequate service lives, that means high resistance capacity to wear, camshaft running faces are hardened, for example in the laser beam remelting process.
It must be ensured in this process that the martensitic microstructure is developed uniformly over the camshaft contour by exact thermal processes and time sequences.
This process is checked by means of hardness testing. This calls for a method that keeps the necessary time expenditure within certain limits even with statistically required multiple measurements.
For this purpose we recommend the hardness test according to the UCI method (**U**ltrasonic **C**ontact **I**mpedance).
When using the well known Vickers method, the indentation area of the diamond has to be determined using a microscope. The hardness H then is expressed according to the relation

$$H = \frac{F}{A}$$

where F is the indenting Force and A the indentation area.

In case of the UCI method, the Vickers diamond is mounted on a vibrating rod, which changes the vibration frequency during the indentation process. The frequency change is proportional to the indentation area. This allows a fast and mobile test procedure because the microscopic area measurement is no longer necessary.

Using the test load of 0.3 kgf (3 N) and 1 kgf (10 N) respectively, an approximative nondestructive surface hardness determination is achieved (experience shows that the indentation depths of Vickers diamonds are at around 4 to 7 µm).
The measuring process is considerably simplified by the special test support MIC 225 for hardness testing on camshafts. This is achieved by mounting the camshaft in V-blocks and an air bearing slide carriage with probe support guiding the measuring device parallel to the shaft axis. The torsion of the shaft during the measuring process is prevented by magnetic locking, which ensures an exact positioning of the probe on the camshaft base circle or camshaft tip.
The recommended equipment for this application:

- Hardness tester: MIC 10, MIC 10DL
- Probes: MIC 2003-A, MIC 201-A
- Accessory: MIC 225

Figure 21: Camshaft Hardness Testing setup

Besides the UCI-technique further methods for the mobile hardness testing are available: The rebound method and the TIV-method (Through Indenter Vision). The selection of the right method depends on the type of inspection task.

Radioscopic inspection of Aluminium Castings

For the inspection of aluminium or magnesium castings, e.g. wheels, steering housings etc., the X-Ray technique is commonly applied, where the radioscopic method reveals a real time procedure.

The basic setup is shown in Figure 22. The specimen is positioned on a manipulator system between the X-Ray tube and the imaging device – an Image Intensifier or a flat panel detector. The relation between the distances FDD (Focus Detector Distance) and FOD (Focus Object Distance) define the geometric enlargement of the displayed object details.

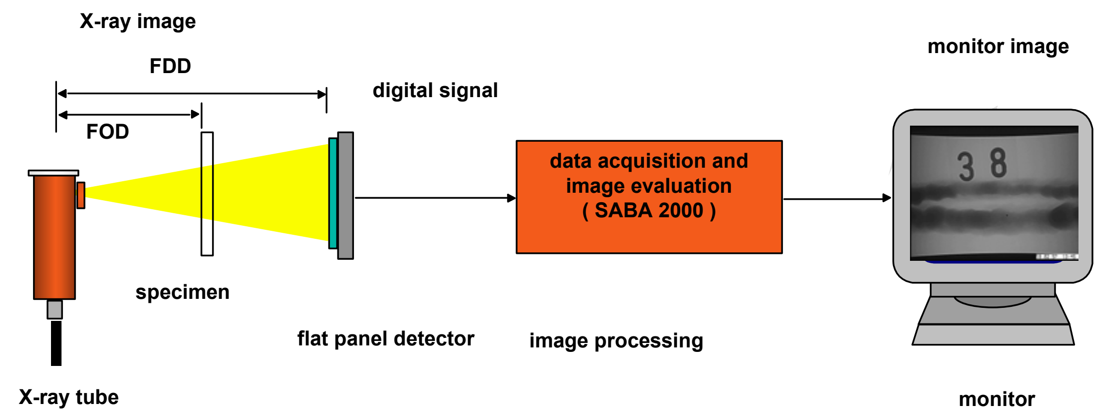

Figure 22: Radioscopic Setup

The digital image signal is displayed directly on a monitor or can be processed, in order to automatically detect (computer aided) flaws.

Figure 23 presents a view inside a radiation protection cabinet, where a steering housing is mounted on the manipulator. In the upper left corner a radiographic image is included.

The available contrast of the radioscopy permits detection of flaws with minimum extensions of approximately 1% of the actually penetrated wall thickness. The lateral resolution depends of the focal spot size, the geometrical magnification factor and the resolution of the imaging device.

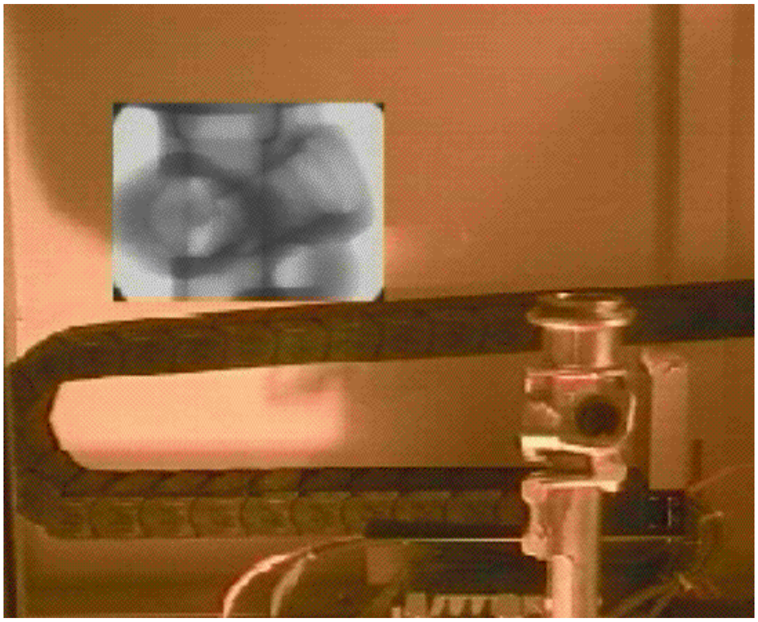

Figure 23: View inside a radiation cabinet and a radioscopic image of a steering housing

3D-Computer Tomography

X-ray transmission techniques such as radiography and radioscopy, deliver “shadow” images without any information about the depth of a flaw or any geometrical indication.

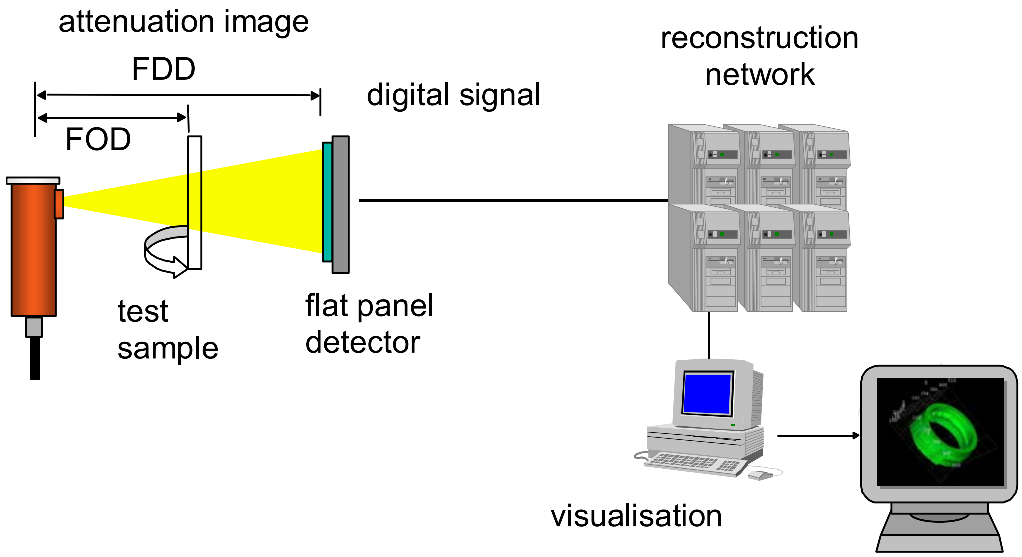

Figure 24: Setup for the Computer Tomography

The complete information however can be obtained using tomographic methods. Here, the test sample is rotated in the X-ray beam, see Figure 24, and the intersections of the object or even three dimensional images are obtained by means of a computer reconstruction.

Highly sophisticated computer tomography allows detection and localization of flaws such as gas pores or shrinkage cavities and the determination of geometrical properties such as internal wall thicknesses and core mismatches. For example the 3D-CT is used for the inspection of motor blocks or hydraulic labyrinth systems or pump housings, as shown in the Figures 25 and 26.

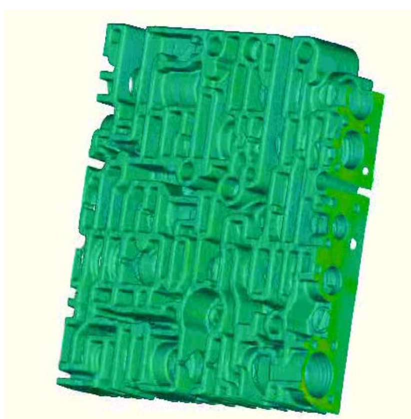

Figure 25: 3D-Tomogram of a hydraulic labyrinth block

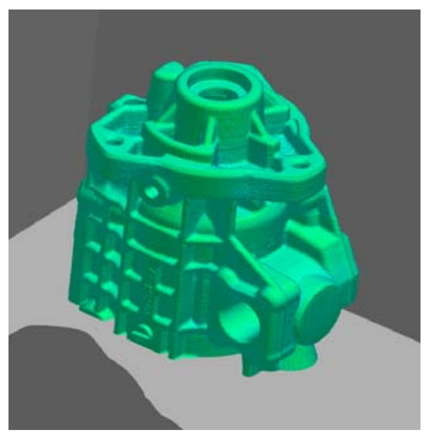

Figure 26: 3D-Tomogram of a pump housing