INSPECTION SOLUTIONS FOR THE AUTOMOTIVE INDUSTRY – SPOTCHECKER AND USLT-USB

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Introduction

The almost globally existing liability act for manufacturers, specifically OEM´s in the automotive industry always leads to the need to take a closer look to the safety of cars and transport vehicles. For instance, within the Russian Federation the liability of producers is well-regulated in the Federal Law "*On Protection of consumers*", art. 13 and 14 "*Liability of producer for violation of consumers' rights*" and "*Property liability for damage resulting from faulty goods (works, services)*". The producer shall be made liable for subsequent loss or damage independent from the guiltiness for claims caused by a faulty product when lifes, health or property is concerned. In difference to the European situation there´s no chance of exculpation, means that the liability remains even when the manufacturer can expose and proof that the supplied products fullfil the appropriate safety regulations for e.g passenger transport and, even more important, even if he can proof that compliance to these codes and specifications is given by tests as per state-of-the-art technology (according to the item 5 of article 14 of the mentioned Law "*On Protection of consumers*" there is an exemption from this general rule, namely: "5. The manufacturer (executor or seller) shall be absolved from liability, if he proves that harm has been inflicted due to force majeure or the breach by the customer of the set rules for the use, storage or transportation of goods (works, services)").

The industry must meet the requirements for increased safety (product liability), the tightened regulations regarding environmental protection, as well as the wishes 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 into an economic way of acting.

While a downright „outsourcing frenzy" was to be noted among the manufacturers during the nineties, this has given way to a certain pragmatism for some years now since the expected cost savings did not stay within the required limits. Amount of coordination, loss of control and information, and more intensive thoughts about the core competences are now influencing the trend towards „insourcing".

The industry will have to invest in safety and quality in the future as well because the conditions related to the product liability will continue to lead to recall actions and other cost-intensive measures. Advanced processes will be in demand; not even the use of new joining techniques and materials will alter anything about this fact.

Applications and Tasks

Since the increasing demand of higher qualities the cost ratio should be strictly monitored as well. Documentation in an online process as well as most precise and automatic defect recognition stands against high scrap costs due to destructive cross-checks or redo/recall-scenarios. With focus on advanced inspection solutions on cars the field can be devided in 5 areas of interest. Subsequently there´s more than 50 solutions and 250 solved applications, adressed with various inspection methods.

Pic. 1: Car breakdown to major inspection areas

The database for inspection solutions includes methods like Hardness Testing, Visual Inspection and surveillance, Radioscopy / CT, analytical X-Ray, Eddy Current and finally Ultrasonics, primarily focussing on the body shell, engine/drive train components and safety parts.

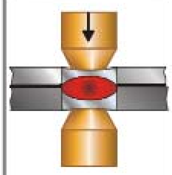
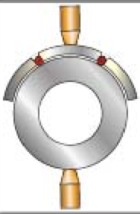
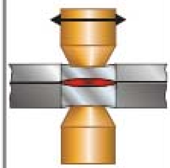
It seems obvious that in terms of adressing all the existing concerns and monitoring needs proper pruducts must be found that cover more than one application only. From the Ultrasonic Testing (UT) perspective there is several options and modules available, all connected to an instrument called Spotchecker, e.g. inspection of:

I.	Spotwelds (linear):	UltraLOG Software package
II.	Spotwelds (structurized):	Database Manager Software package
III.	Statistical evaluation of I and II:	UltraCar Software package
IV.	MIG/MAG welded joints:	USLT 2000 package
V.	Circular, resistance-welded joints	USLT 2000 package
VI.	Tailored blanks:	USLT 2000 package
VII.	Hardness Depth inspection:	EHT plugin for USLT 2000 package

The biggest advantage here is most probably the chance to work on battery power up to 5 hours with one charge and hot-swap capabilities, but even more important the Bluetooth and WLAN options that enable the operator to key in, transfer or print any data or report wirelessly.

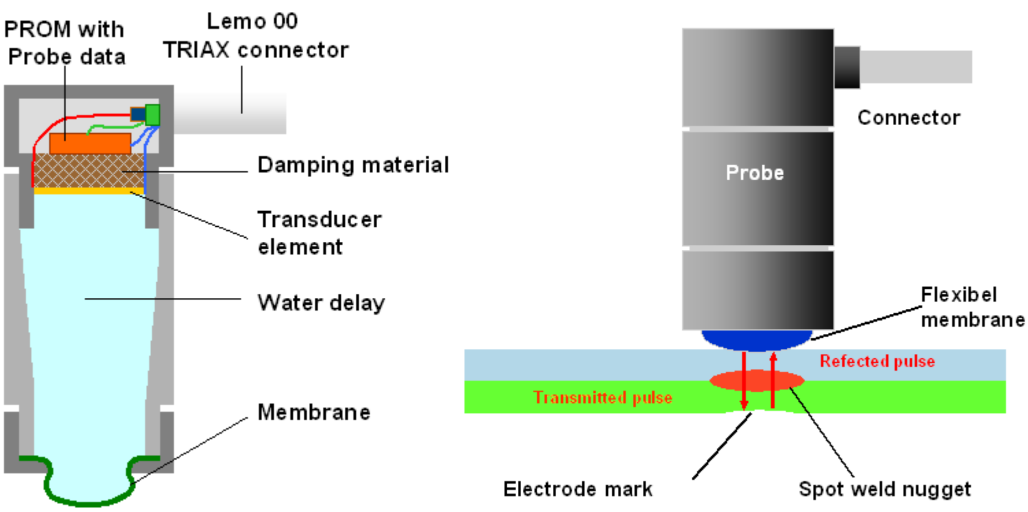
I. UltraLOG Software package

The mostly used joining technique for the assembly of car bodies obviously is spotwelding. In general this can be devided in three different methods: Resistance welding, hump welding and ultrasonic welding (see Pic. 2). In the following we will concentrate on the first, resistance welding only, subsequently the inspection of the generated spotwelds.

Joining method	Principle	Material	Automotive part	Test method	Comment
Resistance welding		Two or three layers - Steel, - Stainless steel, - Aluminium and other non ferrous materials - Coated and uncoated	- Plates - Body parts	Ultrasonic Puls Echo	Defect types: - Loose - Stick weld - Bad through welding - Burnt - Small nugget - Gas pore 
Hump welding		Two layers, one plate with small humps - Steel - Stainless steel - Aluminium and other non ferrous materials - Coated and uncoated	- Body parts - Mounting parts	Destructive	Ultrasonic is not possible since - the surface of the spot is like a hump
Ultrasonic welding		Two layers - Aluminium - Plastics	- Reflectors - Other interior parts	Destructive	Ultrasonic is not possible since - the surface is to rough (steel)

Pic. 2: Joining technologies for spot welding

Despite the necessity to take advantage of sophisticated software (here: UltraLOG, based on USLT 2000) the operation of it deems as easy as 123 due to the so-called wizard-function that leads the operator through the process of setting-up a spotweld inspection by a simple step-by-step guidance. Goal is to teach the instrument to all relevant inspection parameters like number of plates/layers (3 max.), thicknesses or the appropriate UT parameters, as well as the definition of the Spotwelds incl. numbering and the specific quality criteria.



Pic. 3: Principle of UT on spotwelds

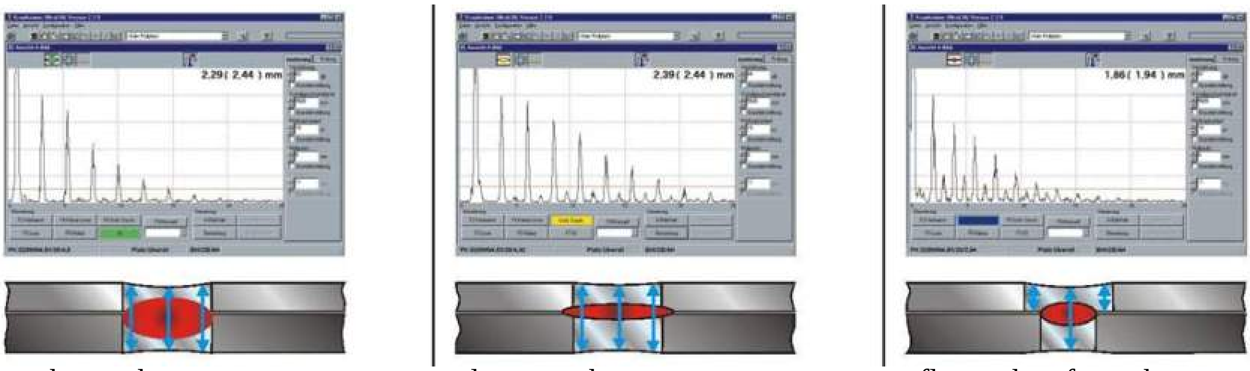
The sound (in particular logitudinal waves), generated by the piezo-electric effect with a single element, high frequency transducer (bandwidth depending on the application, between 10-20 MHz) will be transferred through the water chamber underneath the element inside of the probe towards the spotwelded plate combination. The flexible membrane fits perfectly to the surface indentation created by the electrodes during the welding process.

During the insonification the sound will pass the welded zone (“nugget”), be reflected from the backwall and return the same way back to the crystal to be received and finally displayed again as an amplitude vs. time signal. For the evaluation we have to look into the echo sequence, given by the “bouncing” sound forth and back between surface and backwall. With changing spot qualities the grain structure of the welded zone changes, as well as the nugget size obviously influences the transmission of the sound.

In order to keep the theory simple we assume the sound beam behaves like a laser: Straight down without any angle of divergence over the propagation. Also we consider the sound field diameter to be equal to the element diameter generating the waves. This would mean we need to select a probe having the same element = sound beam diameter like the perfect nugget size would have, so that in case of a changing nugget diameter or grain structure (effecting the souund attenuation) it would most probably give us a different corresponding A-scan.

In principal, e.g. on black carbon steel the differentiation of spotweld qualities on a typical UT image (A-scan) may look like shown below in Pic. 4a/b.

OK | *bad through-welding* | *small nugget*



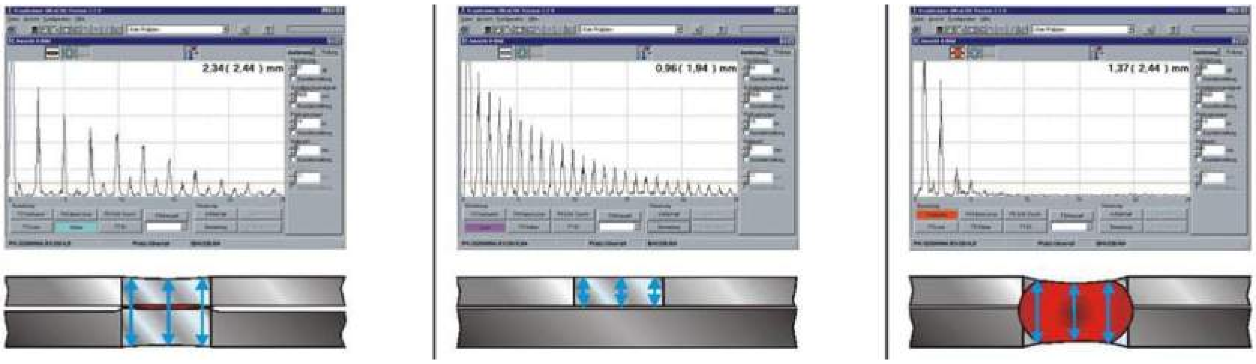
OK:
- short echo sequence due to high attenuation of the sound
- no flaw echos

bad through-welding:
- longer echo sequence due to reduced attenuation of the sound

small nugget:
- flaw echos from the unwelded area

Pic. 4a: Signal display and automatic defect recognition on black carbon steel plates

Sticked weld *loose* *burnt*



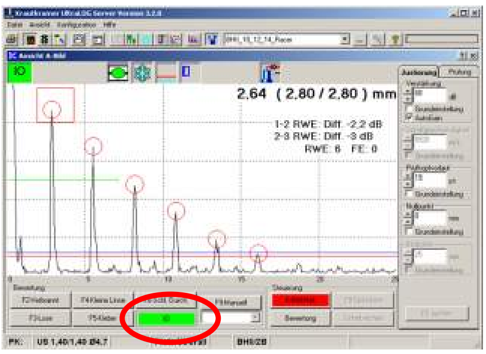
- long echo sequence due to missing weld
- "Napoleon hat"

- long echo sequence, insonification of the upper plate only

- short echo sequence by strong attenuation

Pic. 4b: Signal display and automatic defect recognition on black carbon steel plates

Basis of all this is the combination of a high-performance flaw detector, the USLT 2000, in conjunction with the appropriate software to acquire, compare and display the final results, namely the all-in-one package: Spotchecker, which also can be retrofitted with all other above mentioned packages, should it be required. Furthermore, once the UltraLOG (spotweld inspection software) has been set-up correctly, by taking advantage of the in-build "Evaluation Assistance" the system will constantly display the inspection outcome at the end of each acquired and frozen A-Scan (see Pic. 5).



Pic. 5: Automatic Evaluation in freeze-mode (OK)

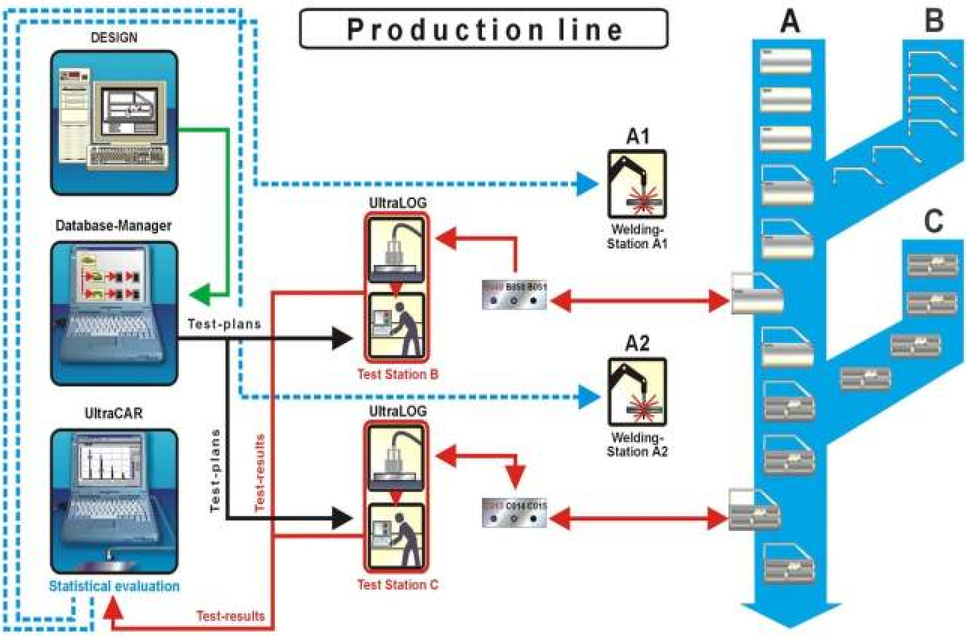
II. Database Manager Software package

The "jump" from a linear (= unvarying batch) inspection to the complex, structurized inspection is just a software away: Here the Database Manager comes into the picture.

The term "structurized" describes the typical scenario that one find in an automotive bodyshop: It´s not the fully set-up and build car body that should be inspected by UT, but the single components at various steps within the production process.

For tracability reason this should be directly linked to the welding process as well as the different possible add on inspections, such as hammer and chisel or visual testing. Pic. 6 shows an example how the quality surveillance may be linked under these preconditions.

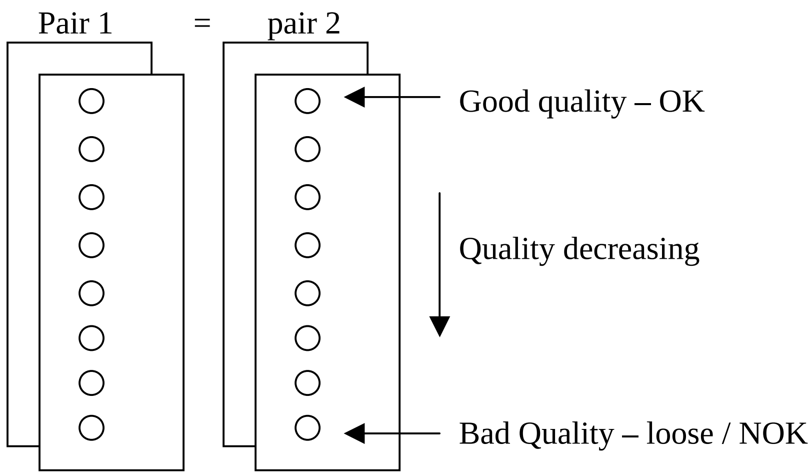
The goal is that, once the UT system has been teached about all these appropriate parameters and details the final report should give more than a possible faulty spot information, but also the direct feedback on which robot or hand gun is responsible for this spot, so that immediate action can be taken in order to save precious time. Moreover, depending on the acceptance thresholds the UT inspection outcome should bring the information of a decreasing quality just before a spotweld turns to become bad.



Pic. 6

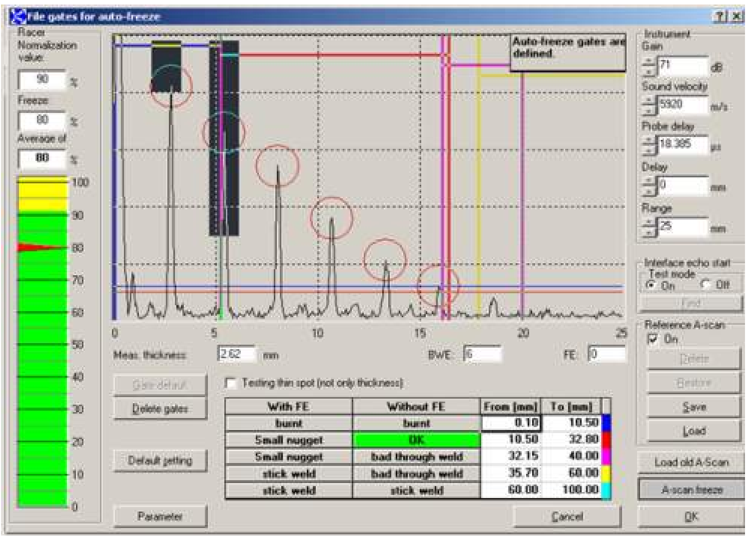
What does this mean in practice?
First of all, in order to get precise information about the spotweld quality it deems necessary to start with correlation tests. All possible plate combinations that should be monitored with UT should be taken for test plates with all occuring defect types. These plates must be existing two times each – one for the destructive (tear-down) countermeasurement and one for the UT investigation to compare against.

For example, if the area of interest is the left front door, inner part, rear side with a plate combination at this position of two plates, 0.8 mm (top) and 1.0 mm (bottom), then we must take this 0.8/1.0 mm combination and get some test strips welded with an OK, burnt, bad through welding, small nugget, sticked weld and loose weld spot – and this strip then again must be existing two times for the correlation mentioned above.



Pic. 7

According to this the evaluation assistance will be trained so that later on we can easily distinguish between the different quality levels, proffed by the correlation we did upfront.
Pic. 8 shows a typical set-up screen on the Spotchecker where also the gates for the automatic freezing of the A-scan will be defined.

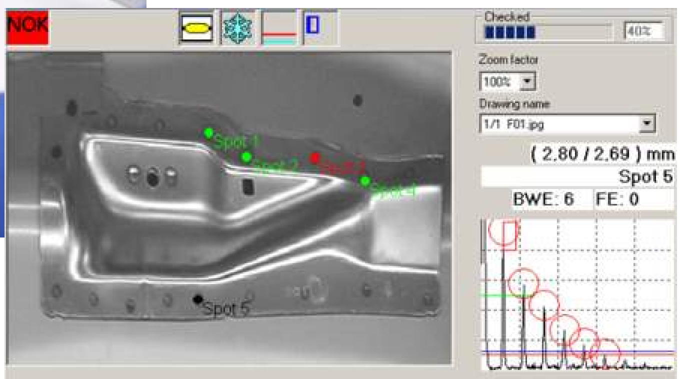


Pic. 8: Spotchecker screenshot

Then all the different names and positions of the rest of the spots, according to the breakdown model of the bodyshell should be entered, together with the welding station definitions. Finally we could take either the original technical drawing of the object of interest or, alternatively a photo of it and insert this to the inspection plan.

Under these preconditions the operator can make use of a quite simple inspection screen, where he sees the objest he´s supposed to inspect right on his instruments´ screen. In the moment the inspection starts the spot he should start with will start flashing on his screen, indicating the position for orientation so that he may find it easier on the real specimen in front of him ("spot following").

Once a proper echo sequence has been obtained the A-scan gets frozen and evaluated automatically, showing the result also on the photo as the spot will get the color of either red or green, depending on whether it was a bad or a good one (see Pic. 9).



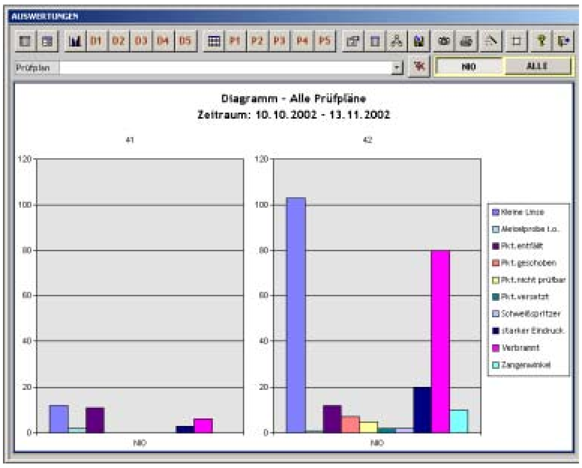
Pic. 9: Either way is possible…

Considering that each vehicle is build with between 3000 up to 7000 spotwelds, this inspection can drastically reduce the formerly created scrap costs when parts and even complete bodyshells were destroyed completely. Nowadays, since the use of high strength steels (HSS) becomes more and more important the destructive tests diappear completely as the efford to tear them down would be way too high (the material is simply too hard) – so UT deems the only option here. The combination of the non-destructive defect evaluation – even for less-skilled operators in conjunction with the possible corresponding direct welding process control at a very early stage is what will be adressed when taking advantage of this cutting-edge technology.

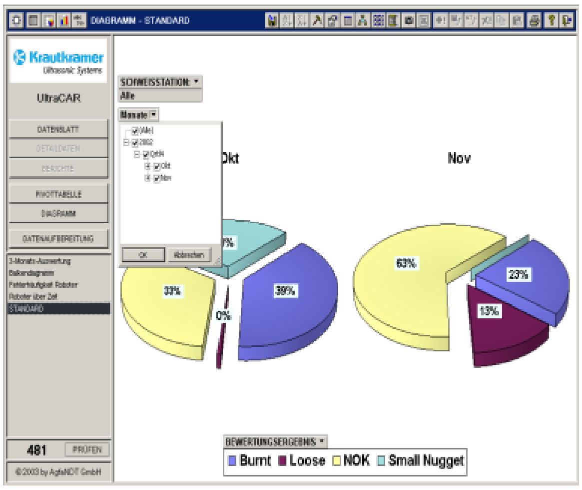
III. UltraCAR Software package

Once the inspection sequences were executed the way of reporting deems important to the users. The reports generated by the system give an excellent start into statistical evaluation and documentation, which in turn can be done by the UltraCAR software. Assuming the inspection plan was generated by the Database Manager, where all object and inspection criteria were filled in, all reports can be easily tranferred wirelessly (e.g. LAN) into another PC where UltraCAR is installed for post-evaluation.

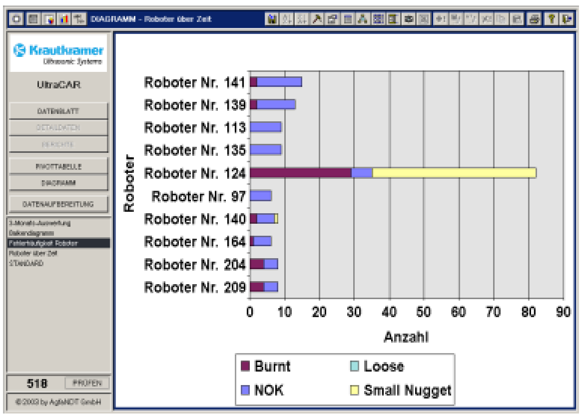
This in turn could mean that at any time the managers, administrators or specialists from Body Shop, Welding, QC or any other department that may have an interest in the inspection results can easily obtain tables, diagrams or other graphics showing the current situation as well as the trend analysis just by a push on a button (considering the requested data were predifined). The following pictures show some examples on how such information can be used (Pic. 10-12).



Pic. 10: weekly comparison on all inspection results, OK vs. NOK



Pic. 11: Flaw distribution analysis – 2-months comparison



Pic. 12: Scoring the welding robots - which one needs to be overhauled/tip dressed?

IV. Inspection of MIG/MAG welded joints

In general, there´s a lot of different joining technologies being used on cars and transport vehicles. Apart from spotwelding other joining techniques need to be monitored and checked, too. MIG/MAG welding, for example, which is an arc shielded gas welding method quite frequently can be found on e.g. internal or door hinges. The inspection requires a specific probe combination to be used on a standard, high-performance UT flaw detector, such as the USLT 2000 (basis of the Spotchecker) in so-called through transmission mode.

Principle	Material	Automotive part	Test method	Comment
	Welding current melts the additional welding wire - Steel - Stainless steel - Aluminium	All parts of the body or accessories which have to be joined with the body - Plates - Hinges	Ultrasonic Through transmission	In many cases there is not enough space for the probe access from both sides. Defect types: - Unbonded 

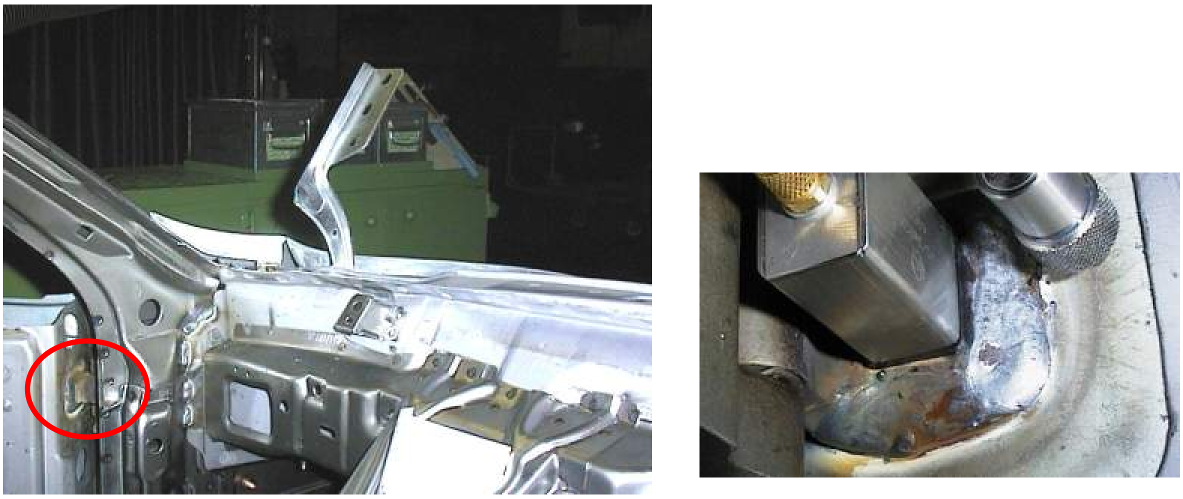
Pic. 13

Depending on the welded materials, but also accessability and sizes there´s various different probe options available, all running in T/R mode (=transmitter/receiver, one acts as the emitter, the other as the receiving transducer; both wave types are possible: longitudinal as well as transversal=shear waves).

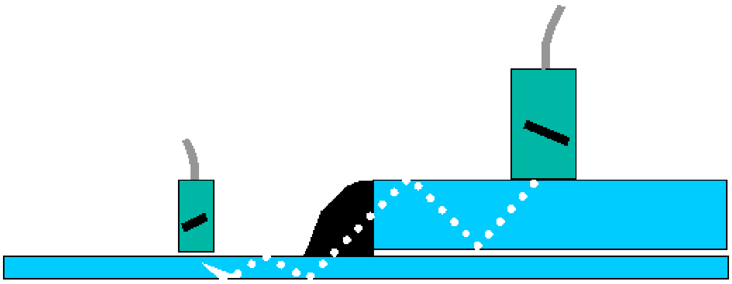
Example:
The hinges on a left front door need to be inspected. The type of defect we would like to determine is a possible unbonded area. We use a special probe (Pic. 14) , equipped with 3 elements inside acting as the pulse-emitting device.

Pic. 14: MIC/MAC probe in sideview (left), and bottom-up

As the elements "look" into different directions we may scan around this probe with the second, the receiving counterpart in order to get the transferred sound collected and displayed (Pic. 15, 16).

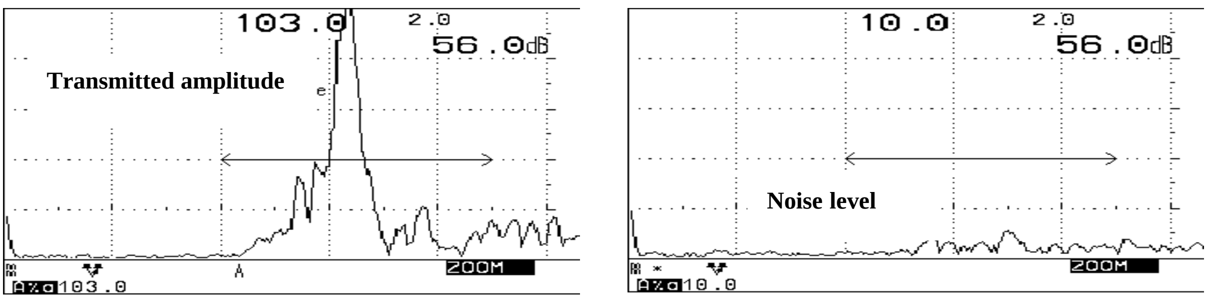


Pic. 15: situation in production (left), detailed view when applying probes (right)



Pic 16: Schematic positioning and sound transmission in good condition

The evaluation is simple: As long as the weld seam shows good bonding the sound will pass through and can be received the other side (amplitude signal high), if defects like porosity or cracks harm the transmission the signal will decrease – worst case is complete disbonding where we do not see any signal anymore (Pic. 16).



Pic. 16: Good bonding (left), disbonded (right)

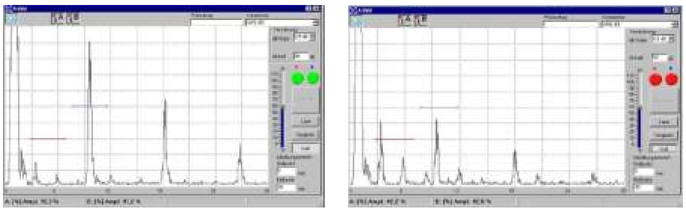
V. Inspection of circular, resistance-welded joints

Another, often used joining technique can be found on circular joints (Pic. 17). In this example we have zinc coated plates with resistance-welded insert nuts. The inspection is being done using the special probe K8GNE on the USLT 2000 software. This probe is equipped with an annular element, suitable to the supposed weld seam width. The tranducer needs to be applied on the plate surface and inserted in the nut by the spigot to get a reproducable positioning over the weld (Pic. 18a).

Pic. 17

The inspection is to be executed without rotating the probe. A proper welding will appear as a “normal” echo sequence of the total thickness on the corresponding A-scan, areas with weld gaps will be displayed with intermediate echoes from the bonding zone (Pic. 18c/d).

Pic. 18a: Insertion



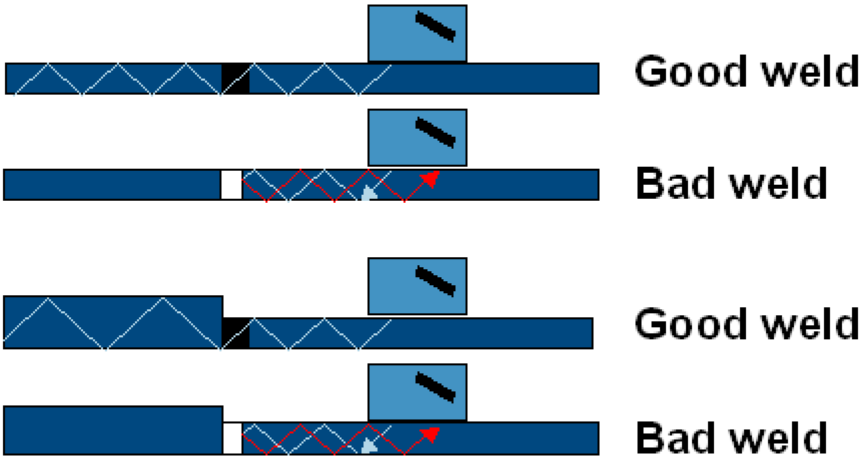
Pic. 18b: A-scan with OK (left) and NOK (right) result

As shown in Pic. 18b the “OK” situation appears with the first backwall echo (BWE) at about 90 % screen height whereas the “NOK” scan shows a drop by 50 % together with an intermediate indication rising from 15 % to 40 %.

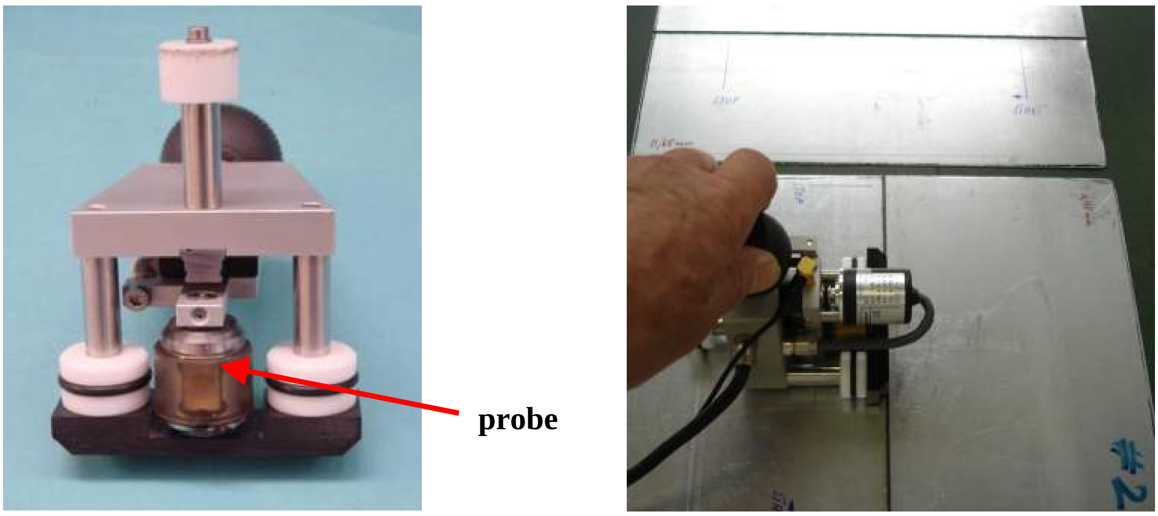
Using this amplitude information we can clearly identify and differentiate between good and bad welding. Height and logic of the used evaluation gates must be set as per correlation tests prior to the inspection.

VI. Inspection of tailored blanks

Within the field of laser welding tailored blanks are often used to connect/join plates, even at side the steel suppliers. Two parallel plate edges will be welded together with no overlapping, where the plates can also have different thicknesses. Tailored blanks will reduce the costs and the weight, as well as they improve the corrosion resistance, depending on the choice of materials. Typical defects that may occus are undercuts, porosity or simply no welding over a certain distance. The preferred UT method deems pulse echo where only one tranducer is being used (Pic. 19). The systematic problem is that the plates may not be flat anymore when the inspection has to be done- curved surfaces plus the edge at the welding zone make it difficult to guide the probe alongside the seam to monitor its quality. A roller probe, specifically designed for tasks like this seems the preferred choice (Pic. 20). A big advantage of using roller probes is the operation without any couplant! Depending on the inspection environment difficulties various modifications are possible as well (e.g. T/R, motion encoding, etc.).



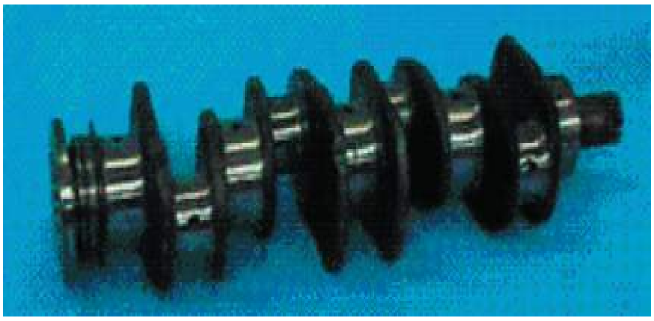
Pic. 19: Inspection method – tailored blanks



Pic. 20: Roller probe (WRL-B7), no motion encoding (left), with motion encoder (right)

VII. Hardness Depth inspection

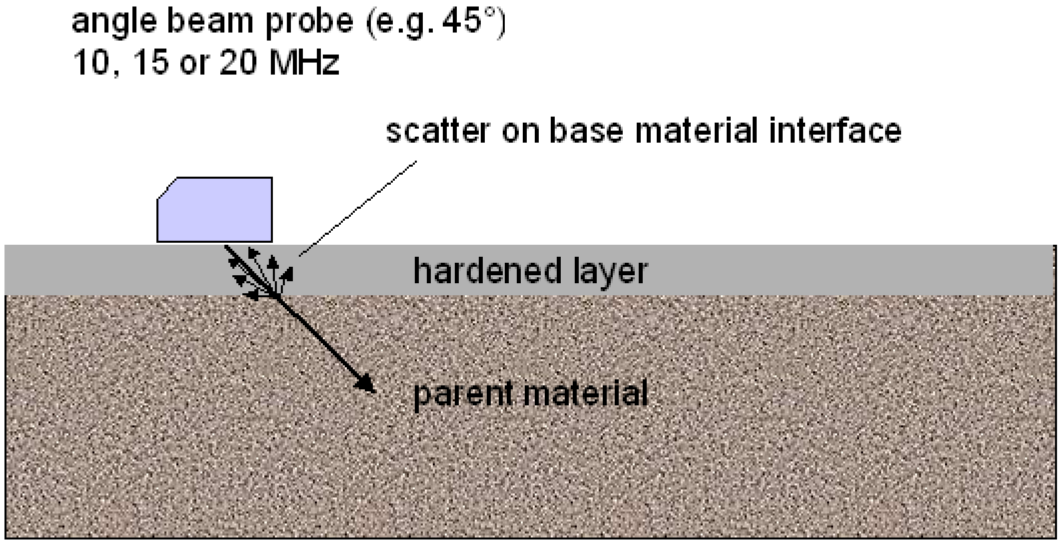
Some engine or drive train components of a passenger car need special attention with regard to an optimization of the ductility / hardness ratio. E.g. crankshafts or camshafts undergo a certain hardenig process. The hardening depth on the running surface of a camshaft normally is determined destructively by means of metallography (Pic. 21). However, the destructive metallographic test is time consuming and quite expensive. A proper alternative would be the ultrasonic "backscattering technique". Due to the fact that thermally hardened materials appear fne grained in the hardened, but coarse grained in the nonhardened zone this method can be easily applied by selecting an ultrasonic wavelength that is just a little larger than the grain size in the hardened area and somewhat smaller than the one in the base/parent material. Subsequently scatter indications from the transition area can be measured – consequently also the hardeness penetration depth. An easy and reliable evaluation is possible when using the Spotchecker / USLT 2000 option EHT (abbreviation for the module "Einhärtetiefe"), limitted only by the hardening methods (thermal hardening only), such as flame-hardening or inductive hardening, for example.



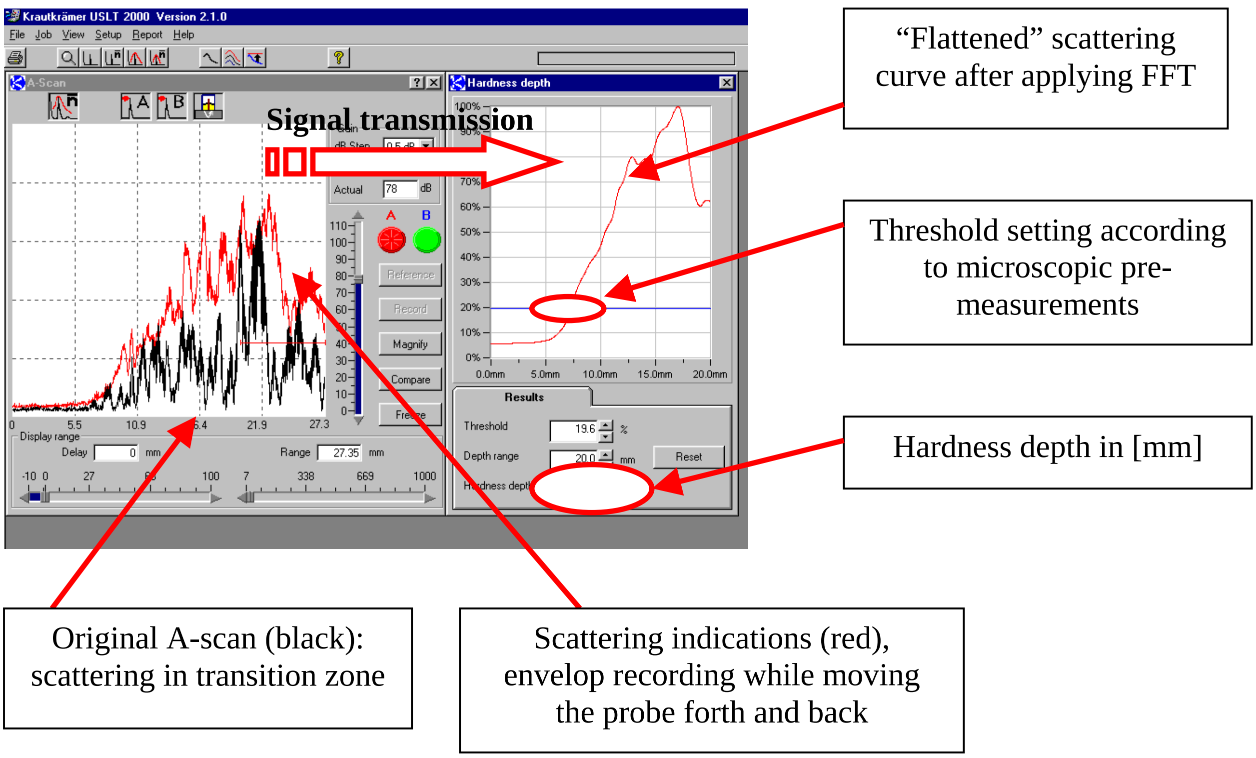
Pic. 21: metallographic determination of the hardened depth, here: crankshaft

The procedure is considerably easy, as like in conventional UT this inspection is comparative, too. The first step (=calibration) is given by the metallographic and microscopic measurement of a relevant specimen, representing the certain material properties equal to the ones of the objects of interest. In addition a high frequency probe with a center frequency between 10-15 MHz should be taken in order to obtain the UT countermeasurement. Finally the threshold to the destructively observed value must be adjusted on the Spotchecker EHT Software plugin, so that now UT corresponds to the standardized metallographic rating. This can be seen as a one-time adjustment as from that time on all other parts showing equal parameters can be quickly tested without any other preworks.

Example for manual hardness depth testing:



Pic. 22



Pic. 23: Signal setup and evaluation

This method is suitable for both, manual but also automatic testing. The limitation is with the hardening process only as only thermally hardened materials can be tested by the UT backscattering method (on chemically treated materials the hardened layer often turns softly into the parent materials´ fine grained structure, thus no real “border” can reflect the sound and create the scattering).

Summary

Saftety and reliability from the customers perspective, as well as cost reduction and quality optimization from the manufacturers standpoint have been in focus for ages, always to be improved and adjusted as per rapidly changing technology demands in the Automotive Industry.

Material processing within the automotive engineering is – in the same way as the corresponding joining technique – subject to permanent changes. New material combinations require new or modified joining techniques. The quality and safety management of manufacturers must be able to react flexibly and economically to the changed general conditions. Combined joining techniques will increasingly be used in the future, e.g. welding and bonding, scotch welding, or clinching and bonding. New materials may sometimes only be joined by means of more complex joining methods. The clear dominance of one single method (resistance spot welds) will diminish in favor of several methods. Resistance welding will nevertheless keep its high status for the short term. As for the test systems, the method chosen first is the one that helps the user to cover as many applications as possible. The ultrasonic method has gained acceptance in practice in this respect. For cost reasons, the equipment used should be flexible enough to enable inspections of several different joining techniques by means of one and the same system.

The recognition and sizing of various defect types like disbonding or lack of fusion, porosity, inclusions, cracks, shrinkage or simple sizing are typical requirements to high-performance flaw detectors. In the world of accelerating performances, where even less-skilled operators are supposed to examine quality issues and report properly into company-owned tracking systems and databases it deems of utmost importance to take advantage of straight-forward and easy-to-handle systems that act on both levels, the “Supervisor” and the “Operator” one, such as the Spotchecker / USLT-USB in combination with the certain dedicated software modules.

The systems used should be open and allow their integration into the corresponding production environment. Manual systems should be largely portable, and stationary systems should fit in the corresponding in-house standard system. It can be expected from the software architecture of test equipment that it accomplishes all common tasks of a quality management via standard interfaces, including statistic analysis according to ISO standard specifications.

Apart from the applications described in this paper there´s certainly way more that have been solved over the course of time, and we will continue to work out even more on behalf of the customer and in the name of quality assurance.