Trends in the Automotive Industry Steer New NDT Applications

Paul BUSCHKE, Walter SCHAPPACHER, GE Inspection Technologies, Huerth, Germany

Abstract. The automobile industry must take the requirements for more safety into account (product liability) in addition to the stricter regulations concerning environmental protection and crash safety as well as the increased comfort requirements of the driver. Costly recall actions, ever increasing demands on quality management and the changing statutory basic conditions with simultaneous, keener competition oblige the industry to take economic action.

The lightweight construction of vehicles (lightweight material and lightweight construction) are of special importance especially owing to vehicle requirements. In addition to the application of new materials, joining and bonding technologies are always being re-evaluated due to technical and economical reasons.

Introduction

The automotive industry

The industry must meet the requirements for increased safety (product liability), the tightened regulations regarding environmental protection, as well as the requests of car drivers for more luxury features. Costly recall actions, ever increasing demands on the quality management, and the changing legal framework force the industry into an economic way of acting, especially with the harsh competitive conditions in the auto industry today.

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 „in sourcing“.

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.

Welded and bonded joints

Improved accessories of vehicles lead to an increased weight. A 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, can only be partly used. Combined methods will replace a single dominant method in the future.

On the other hand, steel makers have also reacted by creating other (lighter) materials due to the increasing competition. The development of low-alloy high-tensile steels aims at making more lightweight and safer car bodies. The design engineer has a large number of the most different materials at his disposal. Steel sheets continue to undergo an electro-chemical coating process (zinc or aluminum) to protect them against corrosion. This also causes problems during welding of the corresponding parts.

The further development of joining technique is also based on two main trends, the combination of different materials and, the use of processed high-tensile steels. Apart from the use of new joining techniques, e.g. bonding or laser welding, the combined methods become increasingly important, for example welding and bonding, Scotch welding, clinching and bonding.

New materials, new joining techniques, new quality standards

Due to the changed conditions with regard to material and joining technique, the 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 welded or bonded joint but also more and more to positively influence the whole process by corresponding measured variables.

The following applications will describe 3 key applications which are forced from the Automotive industry mainly to reduce weigth. Light alloy castings, high strength steel and surface hardening of engine components are typical examples of this evolution.

1. Multi Modality (X-Ray/Ultrasonic) Inspection of casted engine parts

Light alloy castings are widely used, especially in automotive manufacturing. Due to imperfections of the casting process, these components are prone to material defects (e.g. shrinkage cavities, inclusions). On the other hand an automatic inspection solution of this parts is required within the production process.

To fulfill the quality requirements of the industry as well as the economic aspects it is necessary to combine inspection methods. In the current application study we checked the possibility to inspect light alloy casted engines to compare the strength of an Ultrasonic and an X-Ray method.

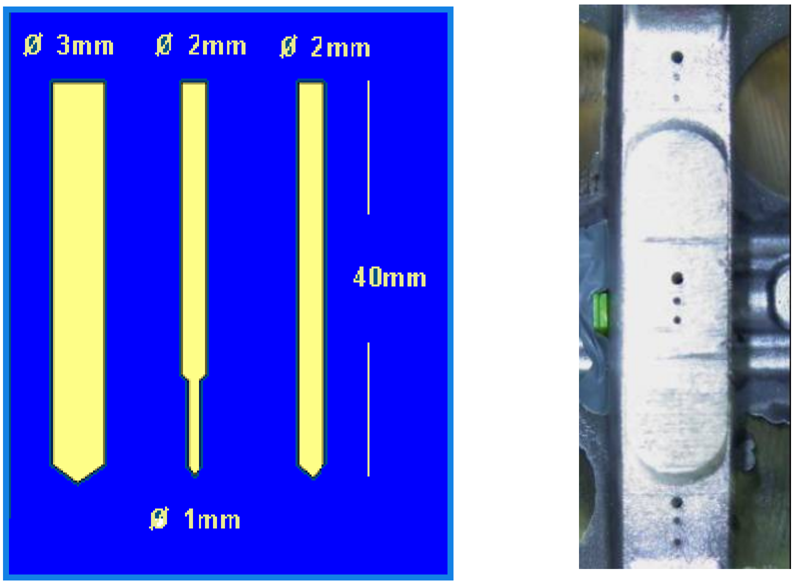
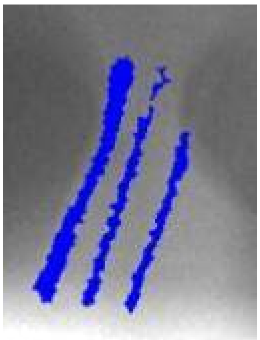


Figure 1. Test hole

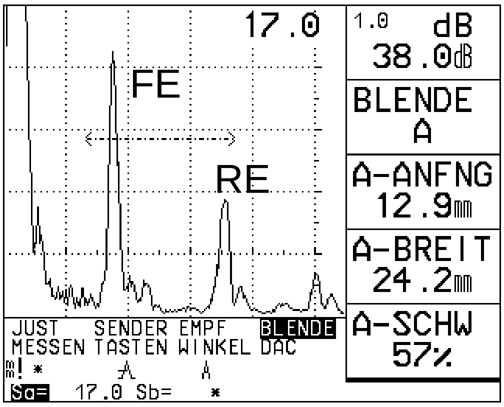
Target was to inspect bearing blocks of an crankcase. Therefore we used artificial flat bottom hole of 1mm, 2mm, and 3mm (Figure 1).

Comparison X-Ray/Ultrasound

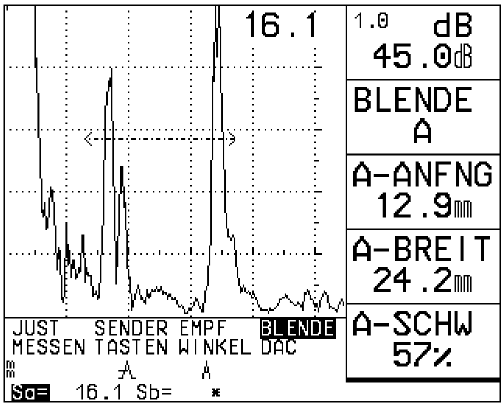
The bearing blocks are positioned on the outer side of the engines as well as within the crankcase. X-Ray Radioscopy of the complete crankcase with automatic defect recognition (ADR) is able to detect wholes >= 2mm. On hipped material the Ultrasound method is able to detect 1mm flat bottom wholes of 1mm with a signal to noise ratio of 12dB. In addition to that with it is possible with Ultrasound to evaluate the structure of the material, which is due to physical reasons with X-Ray not possible. The inspection range and sensitivity depends on the flaws to be detected (coarse or fine material, pores or. If the detection of flaws >= 2mm is necessary it is possible to use X-Ray. If it is necessary to inspect the quality of the structure in addition to that the Ultrasonic method has to be used in combination.



ADR –Detection area of test holes



1. PK: MB4S



2. PK: MB4S

The difference in amplitude of probe no. 1 (Ø 3mm) and no.2 (Ø 1mm) is 7 dB

In the case of the crankcase inspection the decision was made to inspect the whole case and the outer bearing blocks automatically with X-.Ray. The inner bearing blocks will be inspect in addition automatically with Ultrasound.

2. Long life for camshafts

The hardening of a camshaft has a decisive impact on its life. A typical treatment of the camshaft in the form of special hardening and nitriding processes can be carried out and the results checked by way of a hardness test. These specially heat treated camshafts are used not only in production of passenger cars but in particular in racing sports

A hardness value which is too low has negative effects on the camshafts capacity to resist wear. To avoid early pitting, and the development of any disturbing cavities, limit values are defined for the hardness.. A specific test support was designed especially for hardness testing on camshafts. This support is meant to accommodate a UCI (Ultrasonic-Contact-Impedance) hardness tester and its hand-held or motor probe. The camshaft is placed on three V-supports. The center V-support is magnetic and ensures a firm and rigid support on the test object. By actuating a release button, an air bearing slide is manually shifted to the required test position, and locked in its position there accurately to the millimeter.

The running surface is provided with an antifriction and wear-resistant coating. The lowering of the probe and the application of the test load are carried out manually by means of the lever on the support. By easily and accurately positioning the probe on curved surfaces or on geometrically complicated sports, the support helps to achieve a high measuring accuracy in hardness testing.

The design of the camshaft holder makes sure that the camshaft to be tested can be exchanged quickly and easily. The probe positioning and the complete measurement processes are likewise perfectly easy to handle. This system is used for example by renowned automotive manufacturers who carry out a 100% finished-product inspection of camshafts for racing sports. The inspection can be carried out in virtually nondestructive mode with the tiny test indentation of the 1 kgf probe.

In the case of the Ultrasonic Contact Impedance (UCI) method of measurement, the hardness of a material is determined on the basis of the size of the indentation surface left behind in the material by a Vickers diamond after applying a defined load, similar to that of hardness testing according to Vickers or Brinell. Unlike the stationary test instruments, the diagonals of the indentation are not optically evaluated with the UCI method.

The TIV (Through-Indenter Viewing) is an innovative alternative. TIV is a portable test instrument for optical hardness testing according to Vickers while under test load. An optical system including a CCD camera enables viewing “Through the diamond”. This new method makes it possible to directly watch the process of the Vickers diamond penetrating the test material on the display.

There’s no need to subsequently treat the camshaft. Critical soft points are quickly discovered – a reliable operation being only ensured with the correct hardness so that nothing else is standing in your way.

3. Ultrasonic Inspection of Resistance Welded High Strength Steel (HSS)

As a background, the first challenge is to understand the effects that the use of Dual Phase and other high strength steel presents to ultrasonic inspection methods. For example, these metals are more susceptible to producing gas pores in the spot weld, which leads to different ultrasonic behaviors. If the analysis of the ultrasonic signals distinguish gas pores, then the welding engineer must determine if gas pores in the weld nugget are significant to the strength of the weld in order to classify the quality of the weld.

The next challenge is to understand the use of software algorithms integral to the ultrasonic inspection system. In the early days, the quality of evaluation resided in a trained operator’s knowledge. The operator of the ultrasonic inspection would have to place the sensor and simultaneously view the waveform and make the analysis. Today however, ultrasonic inspection systems have built-in software to help analyze the signals. The software is continually being improved to deal with new phenomena and can be used to automatically decide whether the spot weld is good or not or the software can make a recommended decision that can be agreed by or overruled by the operator.

Correlation studies need to continue for improving the inspection processes. Plants that intend to use ultrasonic inspection methods should continue to validate their inspection with correlation studies by first analyzing all spot welds that are inspected by destructive testing methods. Use of plant network systems that link up information from welding controls, welding tools, inspection tools, and destructive test results need to be correlated in order to improve confidence of the non-destructive testing methods.

Background

Ultrasound has been widely used to inspect many different types of welding. In the automotive industry, resistance welding is perhaps the most common weld inspected ultrasonically. The primary requirement for using ultrasound is to non-destructively test the spot weld and classify them as acceptable, undersize, or defective. The pulse-echo method of ultrasonics uses a transducer sized appropriately for a given sheet metal stack up which has been correlated to specific ultrasonic signals received from know weld conditions. For example, Figure 2 shows a typical micrograph of an acceptable spot weld with sufficient nugget diameter and depth of penetration.

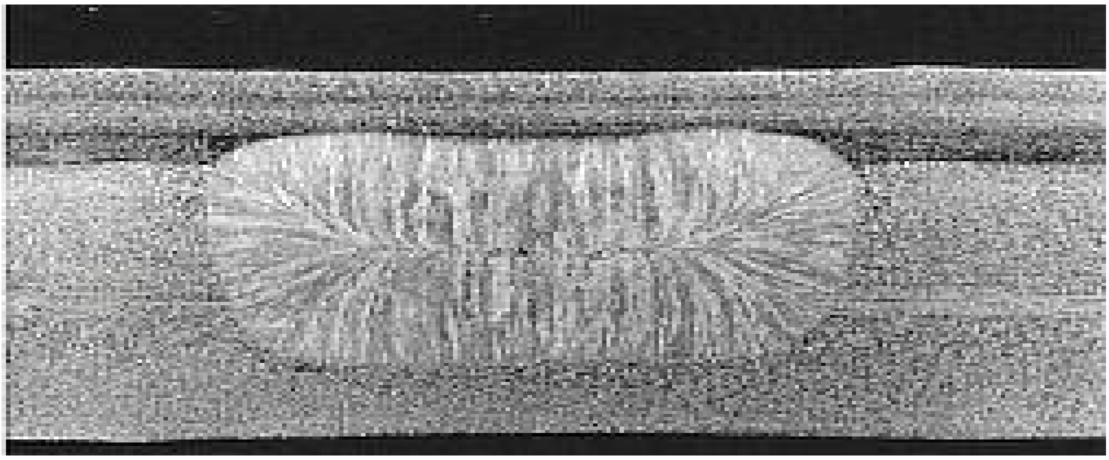


Figure 2. Acceptable spot weld nugget

When ultrasound is transmitted through the weld, a reflection echo pattern is generated and displayed as an "A-Scan", which represents the condition of the welded joint area. If the sound beam generated from the transducer or "probe" is smaller than the fused area, the first reflection echo represents the total thickness of the joined spot. Typically this first reflection or "backwall" echo is used to adjust the ultrasonic instrument gain setting when correlating to a known good weld.

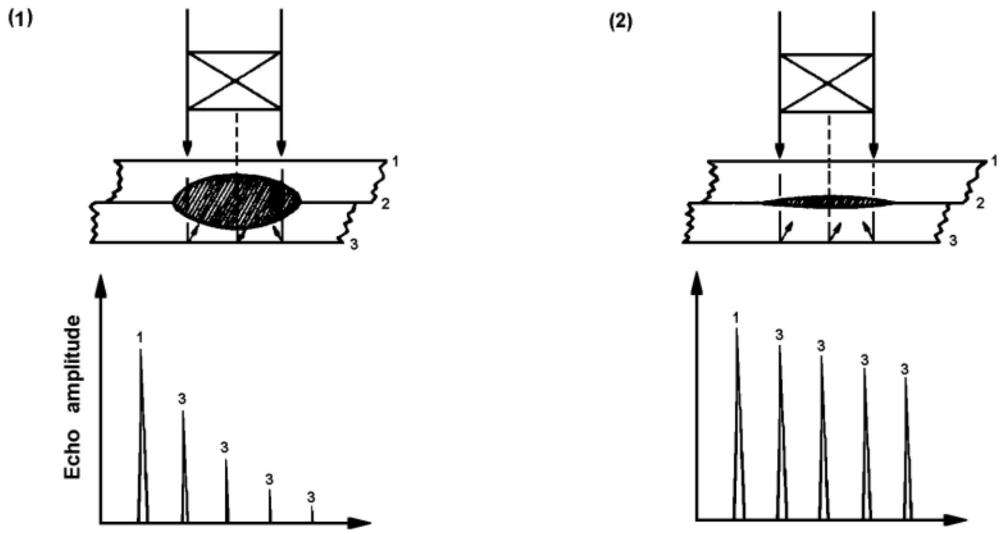


Figure 3. A-Scans showing different attenuation rates

As the wave reflects back and forth between the outer faces of the welded sheets, its amplitude is attenuated. The weld nugget is a cast microstructure with coarser grains than the adjacent parent metal. Therefore, a nugget scatters more strongly than the remaining parent metal, i.e. the nugget produces higher attenuation than the parent metal and a thick nugget produces higher attenuation than a thin one. For this reason, a thin nugget can be distinguished from a thick nugget by the A-Scan rate of decay for nuggets of equal diameter (See Figure 3).

In the case of undersize welds, the sound beam is larger than the weld nugget and sound is reflected at the interface between the welded sheets around the perimeter of the nugget. These reflections from the perimeter of the nugget are displayed in the A-Scan as intermediate echoes between the backwall reflections (see Figure 4).

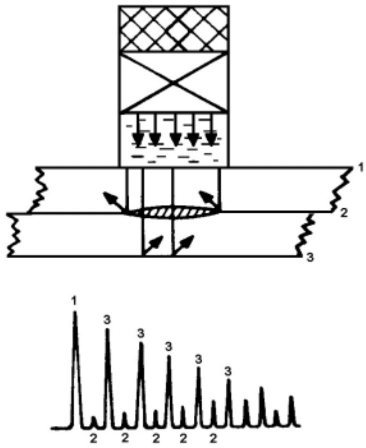


Figure 4. Undersize weld

Intermediate echoes might also be reflected from gas pores or porosity within the nugget (see Figure 6). Gas pore echoes will characteristically be higher in amplitude than undersize weld echoes. The intermediate echo sequence might also be displayed off center between the backwall reflections due to the position of the gas pore as in Figure 5.

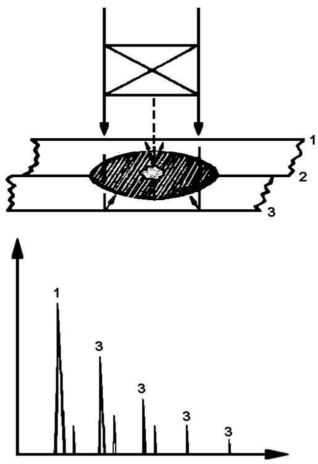


Figure 5. Gas Pore Echoes

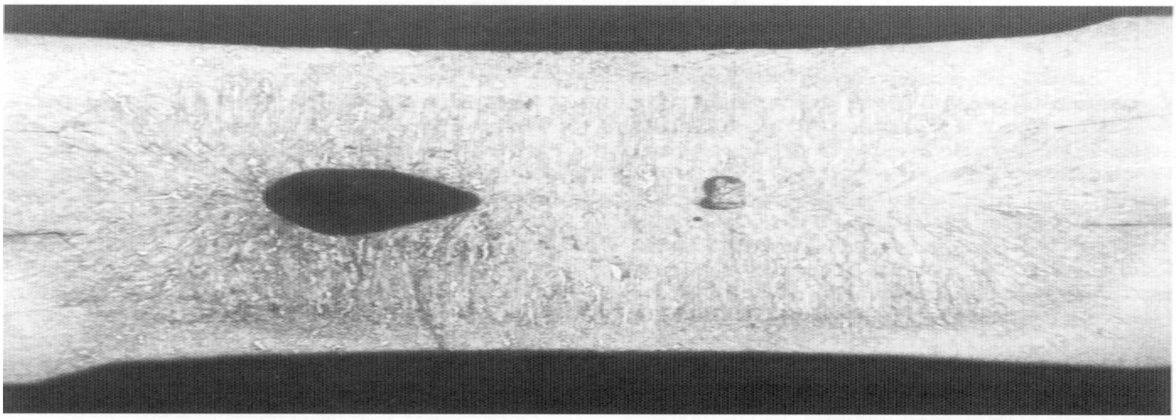


Figure 6. Micrograph of Gas Pore

These gas pore echoes are often confused as undersize weld reflections and cause many problems when correlating ultrasonic results with destructive peel testing. This is especially true with high strength steels. High strength steels are prone to shrinkage, porosity issues, gas pore inclusions, and cracking, more so than mild low carbon steel. And as such require specific welding parameters and weld process control programs to minimize the occurrence of these defects.

Traditional ultrasonic flaw detectors are capable of displaying these echo patterns but the result of the inspection relies on the operator's knowledge and level of expertise in evaluating spot welds. There is progressively more information being evaluated in the A-Scan making it very difficult to visually determine weld quality. It is for this reason that computer based ultrasonic equipment is being used more often than not. With the use of specialized software, specific algorithms can be automatically applied to the A-Scan result, minimizing the training requirements and level of experience of the inspection personnel. In addition, using software tools such as automatic documentation, inspection plan diagrams, and other time saving features can accelerate the inspection process itself.

Test Results of HSS Samples with Gas Pore Inclusions

This test was carried out using the software based USLT2000B ultrasonic flaw detector with UltraLOG spot weld software (version 3.2). The samples were 2mm DP 600 coated sheets, welded together with using 6 spot welds on 1" by 12" coupons. The welds were intentionally controlled to induce gas pores in the nugget. Gas pore samples were then verified using real time digital radiography system.

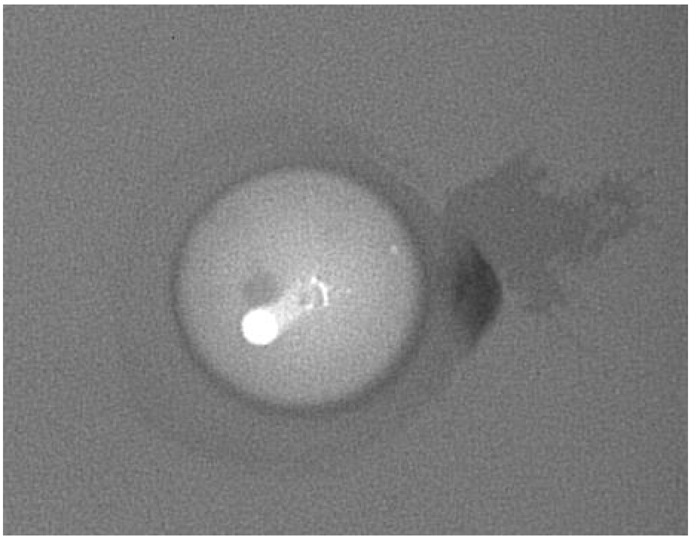


Figure 7. Spot weld sample Plate 2, weld (a).

In Figure 7 a gas pore is clearly seen in the x-ray as a bright white spot located within the nugget area. Here, X-ray imagining detects changes in density or volumetric defects and displays it in gray scale. The darker the gray, the more dense or thick the part is. Air pockets or slag inclusions are less dense and appear light in color in contrast to the parent metal. It is also interesting to note that the zinc corona around the nugget and expulsion are also visible in the x-ray image.

Plate 2, weld (a), was then inspected ultrasonically with a 5.6mm diameter transducer. Using this weld sample as a basis for evaluation, the gas pore echoes were identified and used to calibrate the detection software algorithm (Figure 8).

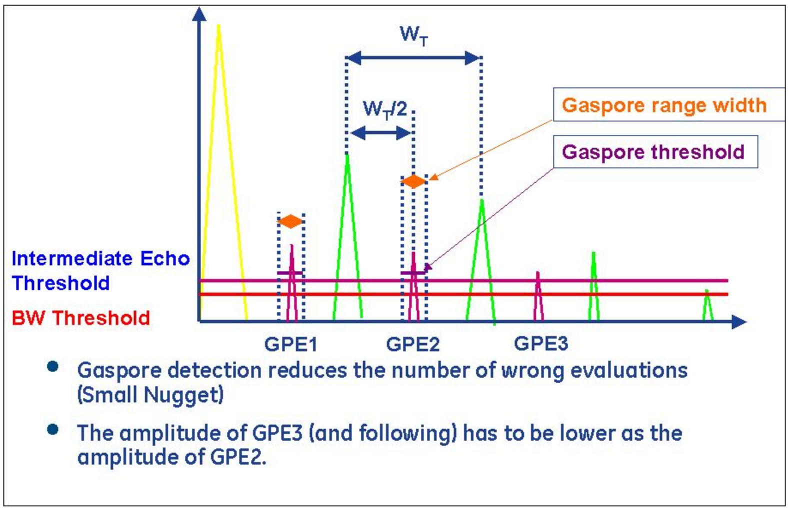


Figure 8. Gas Pore Identification

Once programmed, the software was able to detect, mark the gas pore reflection echo, and evaluate the spot weld automatically. Icons in the software help to visually identify the condition of the inspected weld. The inspector needs only to position the probe on the appropriate spot weld.

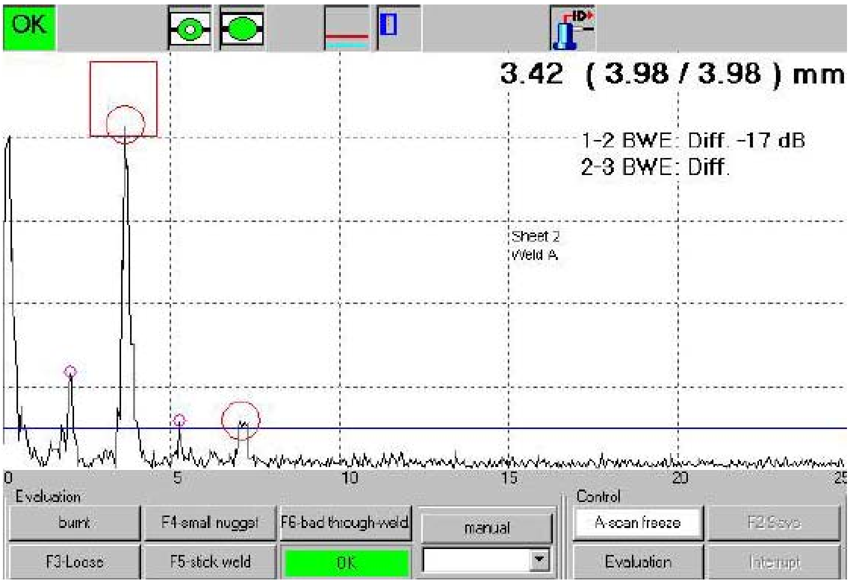


Figure 9. Gas pore detected. Evaluation OK.

In most cases the intermediate echoes would indicate an undersize weld (See Figure 10). However, by interpreting the A-Scan automatically using the gas pore evaluation criteria, the inspection software filters the reflections from the gas pore and evaluates accordingly (See Figure 9). When differentiating the intermediate reflection echoes from undersize welds and gas pores, the software-based inspection becomes more accurate by reducing the amount of false rejects that occur when inspecting high strength steel.

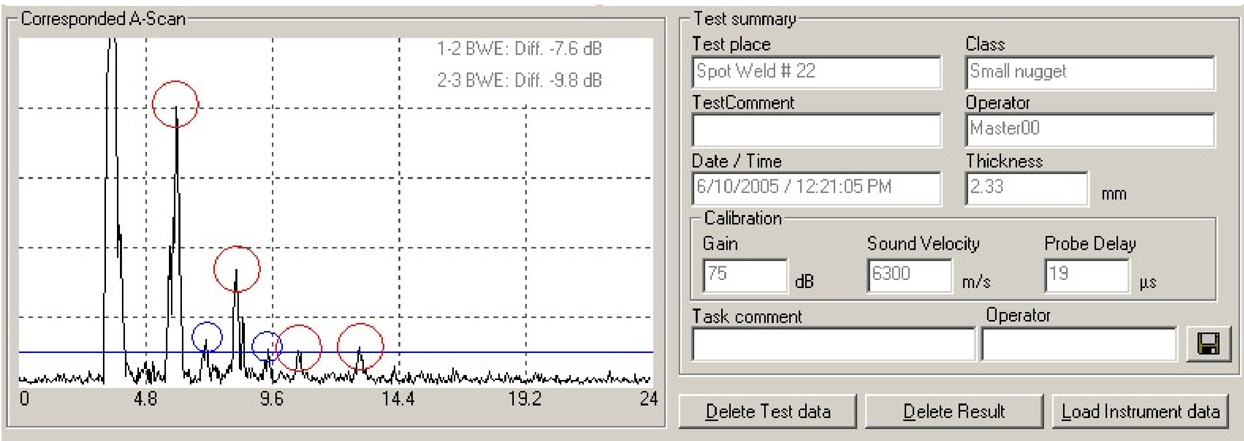


Figure 10. Example of intermediate echoes identified as undersize.

Conclusions

When using ultrasound to evaluate high strength steel spot-welds, special attention must be given to the destructive correlation due to the presence of gas pores and voids in the weld area. The most common mistake is rejecting good welds due to the ultrasonic signals from gas pores. By programming flexible software algorithms to evaluate these signals, the ultrasonic inspection process becomes more accurate in differentiating undersize welds from welds with porosity. As ultrasonic inspection continues to evolve with new materials, it is expected that software based evaluation will become standard practice.

References

[1] Frank Sokolowski, Paul Buschke, Xiang Liu, Xiao Su, Amir R. Shayan, and Dr. Hongyan Zhang, Kip Herner, Reno Boilard "Using Ultrasonic Techniques to Validate Resistance Weld Quality of New Automotive Metals

[2] Long life for camshaft, echo 39 (12/02)

[3] Holger Lux, Werner Roye Application Report "X-Ray/Ultrasonic Inspection of Bearing Blocks"

[4] Buschke, P. "Ultrasonic testing joins it all together on the spot" 2003

[5] Wagner, J. "Spot weld testing of high-tensile steel in the sector of car body construction" GE Inspection Technologies Test Report: 8673/A

[6] Hoppenkamps, U. "Ultrasonic Testing of Spot Welds" 7th edition 2005

[7] Liu, X., Su, X., Shayan, A. R., and Zhang, H. 2005 Ultrasonic correlation of DP600 Steel peel test report. Mechanical, Industrial and Manufacturing Engineering Dept; University of Toledo