Summary
In the modern motorcar production, more than 300 deep-drawn sheet metal parts are joined together by more than 3,000 spotwelds on each car body. To check the spotwelds within the framework of the quality assurance, different nondestructive test methods are available in addition to the destructive methods (tear down test, metallographic inspection): the chipping test and the ultrasonic test, with the ultrasonic test becoming more and more important because, firstly, the chisel test is “not totally nondestructive” and, secondly, the ultrasonic test ensures a clearly higher test reliability [1].

In this article, the basic principle of ultrasonic testing of spotwelds is explained and the latest developments with regard to the computer-assisted test implementation are shown. These include: the automated evaluation assistance tool, the database management for the test results, and the use of dialog probes. Moreover, the aspects of standardization of the method, the training of inspectors and other test personnel, as well as possibilities of a further development potential are discussed.

Basic principle
Spotwelds are nowadays tested manually and in offline mode - manually because no automated testing is possible according to the state of the art due to the non-uniform surface shape of spotwelds; and in offline mode because an online test during the welding process cannot be carried out according to field requirements at present. Figure 1 shows how an inspector positions a probe on a spotweld.

Special probes are used for testing spotwelds. They contain a water delay line with a flexible rubber membrane, please see Figure 2. This ensures that the acoustic wave can be perfectly introduced even in the case of the typically curved surfaces of spotwelds. A sound frequency of 20 MHz is usually chosen. The transducer element diameter comes in stepped sizes between 3.6 and 10 mm.

The soundwaves introduced into the sheet metal result in a repeti-
tive echo sequence from the test object. The quality of the welding is derived from the shape of this echo sequence, please see Figure 3:

1. With a perfect spot weld, the amplitudes of the subsequent echoes drop relatively quickly because the weld structure is coarse-grained and therefore has a high sound attenuation characteristic. The echo intervals correspond to the total thickness of the welded sheets less the electrode indentation.

2. With a too small spot weld, the inspector observes in addition to the normal echo sequence small intermediate echoes coming from the boundary surface between the sheets. This makes it possible to determine whether or not a nugget diameter is smaller than the diameter of the sound beam. This is the reason why probes having a corresponding element diameter are chosen for different nominal nugget diameters.

3. If there is a cold shot or a stick weld, then an extended echo sequence is received from the double sheet. In the case of a cold shot, however, the structure is fine-grained, and this leads to long echo sequence because of the lower sound attenuation.

4. Finally, a non-existing weld leads to a long echo sequence with short echo intervals corresponding to the single sheet thickness.

To determine if a weld nugget diameter is too small, the nugget diameter is compared with the diameter of the sound beam: if the nugget diameter is too small, intermediate echoes are generated. Firstly, this is on the condition that the inspector centers the probe on the spot weld. If the probe is not exactly centered, intermediate echoes are likewise generated. This means that an adequately large weld nugget may be evaluated as “too small”.

On the other hand, however, it is not possible that a too small nugget be evaluated as “good”. Consequently, the test result is always on the safe side with regard to the nugget diameter, provided that the inspector does not make any fundamental mistakes, e.g. use a wrong gain setting or a wrong probe.

Secondly, the comparison of the nugget diameter with the sound beam diameter calls for a high quality of probes. Probe certificates are issued to furnish a documented proof of the sound beam properties. One example is shown in Figure 4.

In the present example, the probe G20MN3.6 was measured, i.e. a probe having an element diameter of 3.6 mm. Widths of 3.5 and 3.6 mm can be read from the sound field cross section with a sound path of 20 mm in water. These widths refer to the 18dB drop referred to the maximum amplitude.

The sound beam cross section is measured with a sound path of 20 mm in water. This corresponds to the working range: in this example, a welded sheet joint of 2 mm in steel corresponds to an equivalent in water of 8 mm. If the sound path of the approx. 12 mm long water delay line in the probe is added, the result is the total sound path of 20 mm in water.

The width is measured referred to the 18dB drop. This is derived from the following correlation: if the first backwall echo is set to a screen height of 80% in the spot weld test and intermediate echoes are evaluated from 10%, this corresponds exactly to an echo height difference of 18 dB. Looking at it from this point of

![Fig. 3: Scheme of basic principle](image)
The computer-assisted spot weld inspection

The type of ultrasonic testing of spot welds described above can be carried out using any portable ultrasonic instrument showing an adequate bandwidth and consequently also the required resolution of the acoustic signals.

With the large number of spot welds to be inspected, however, it takes quite a lot of time to document all results by hand. For this reason, many users today make use of the computer technology in order to automate as many work processes as possible. The notebook-type ultrasonic instrument USLT 2000 is suitable for the mobile inspection. It combines all ultrasonic features with the possibilities of state-of-the-art computer technology.

The application program Ultra-LOG was especially designed for the spot weld inspection. The user interface is shown in Figure 5. It contains the “live” (active) A-scan on the one hand, and the adjustment facilities required for the ultrasonic inspection on the other hand. Moreover, the Ultra-LOG program features the following functions:

- As soon as the inspector has positioned the probe correctly on the spot weld (it is not yet possible to automate this according to the state of the art), the A-scan is automatically frozen. Within the framework of inspection planning, the criteria for the positions and amplitudes of the first two backwall echoes are defined for every metal sheet combination. Once these criteria are met when carrying out the inspection, the computer recognizes that the probe is correctly positioned.

- When an echo display has been frozen, the software issues an evaluation result, in the present example: “OK” since the first evaluation criterion for the drop in the echo sequence, and also the second criterion referring to the intermediate echoes which must not exceed the 10% threshold, are met.

| Probe type: | G20MN3.6 |
| Serial number: | 892 |
| Reflector: | Steel ball, 1mm dia. |
| Medium: | Water |
| Test System: | USD 15 SX |
| AD conversion rate: | 100 MHz |
| Scanner resolution: | 0.1 mm |

1. Cross section of sound beam at s = 20 mm in water (coloured stepping at -6dB, -12dB and -18dB related to the maximum)

2. Longitudinal cut with distribution of sound pressure through the maximum

Evaluation:
18 dB width in the x-axis: 3.5 mm
18 dB width in the y-axis: 3.6 mm

**Fig. 4:** Probe certificate for the sound beam diameter

view, the sound beam diameter is equal to the element diameter.

The question regarding the nominal diameter $D_l$ of the weld nugget now remains. The following formula is usually applied:

$$D_l = 4 \times \sqrt{t} \quad \text{(Eq. 1)}$$

with $t$ describing the thickness of the thinnest sheet [1,2].
If the inspector places the probe on a new spot weld, then the software will recognize this procedure and carry out an automatic storage of the preceding result using the defined name in the inspection plan and the spot weld number.

The test results are stored in a database – either with or without an A-scan. This allows to document the data as well as to sort and read them as required.

When planning the inspection, drawings of the test object can be included, please see Figure 6. This makes it easier for the inspector to process all spot welds in the defined order according to the inspection plan. This dialog box also contains the active A-scan and the tools for evaluating and storing the test results.

As described above, the nugget diameter is compared with the sound beam diameter. This is nevertheless on the condition that the right probe has been connected in each case. Dialog probes are now available for this. They contain a chip including the probe data, e.g. type and serial number. These values are read by the Ultrasonic Notebook USLT2000 so that any possible confusions or mistakes are excluded.

If the inspection is to be carried out not only sporadically but also according to the rules of quality assurance, a detailed inspection plan is required. As with all modern quality assurance measures, this makes an interactive cooperation between the engineering, manufacturing and test departments indispensable, please see Figure 7:

Test reliability, standardization, training

Some users who are faced with the task of ultrasonic inspection of spot welds for the first time, are often very critical about the method. This is a quite understandable attitude and led to the foundation of a study group called “Exchange of experiences in spot weld inspection” a few years ago, joined by almost all renowned automotive manufacturers [1].

Within this group, experiences gathered from the field use in
almost all German automobile manufacturing plants are exchanged and discussed, and open issues are clarified by field-oriented joint examinations.

The positive outcome of the tests described in this article shows that it is possible to mark out an area where a nondestructive ultrasonic test is possible with a sufficiently reliable test result for the practical operation in the field. The systematic continuation of this exchange of experiences will also enable to judge the cases in which a test is still too unreliable at present. Furthermore, it will be possible to reduce the area where there is not enough knowledge of ultrasonic testing at the moment. At the same time, the required scope of training of the inspector is determined within the framework of projects for a directive to be issued by the German Association for Welding Technology (DVS) "Inspector in resistance welding".

Well trained inspectors and uniform test principles are indispensable prerequisites for a successful use of ultrasonic testing.

Comparison of ultrasonic testing with other methods of testing

The shop test methods include the shear down test, the destructive chisel test and the nondestructive chisel test. In the shear down test and the destructive chisel test, the spot welds are subjected to stress until they break using simple test means, without recording a measured value. Used as evaluation criterion is the type of the breakage and the size of the ruptured nugget. The quantity of test scrap causes considerable cost.

The advantage of the chisel test lies in the fact that it can also be used on a finished component, e.g. on a shell. However, it is mostly used as a nondestructive test in these cases, i.e. load is not applied all the way up to the breakage of the welded joint. The costs for this test are comparably low, but so is also the value of its test results [1]. This applies in particular to the nondestructive chisel test. It can only be used for detecting defective spot welds whose strength already lies far below the permissible minimum value, e.g. so-called "stick welds". Besides, due to the relatively indefinite test conditions which cannot be kept constant, the test results vary within wide limits.

The test methods using testing machines include the shearing test, the peeling tensile test, the top tensile test, and the torsional test as standardized test methods. Their advantage is that the strength tested under defined conditions in each case, e.g. shearing load at the breakage of the welded joint, is reliably determined. This statement should be qualified by saying that only information on the strength under the selected test load can be obtained, e.g. the pure top tensile stress, and not on the mixed loads generally occurring. A disadvantage of these methods is the fact that a test on the finished component is not possible.

The metallographic examination enables assessments to be made about nugget geometry, internal flaws, and structure. The good correlation between the nugget geometry and the results of the destructive tests using standardized test methods makes the results of a micrographic examination an important and reliable, if only indirect, assessment scale for the strength of a spot weld.

Three disadvantages limit the application of this test method:

a) The spot has to be destroyed.

b) The test cannot be carried out on the finished car body to be further used.
c) Test costs are relatively high in comparison with all other test methods.

With the exception of the nondestructive test methods mentioned, all other test methods are used in the production. A 100% volume test is nevertheless not possible for economic reasons and, in the case of the destructive test methods, also for technical reasons. This leads to the implementation of sampling tests. It goes without saying that the frequency with the unreliable, yet low-cost, nondestructive chisel tests is higher than with the metallographic examination giving reliable results, yet requiring a lot of cost and energy.

If we look at the test methods usually applied to in-process tests at a higher test frequency and acceptable with regard to their costs, only the chisel test and the ultrasonic test are competitive in principle.

This rough overview of the current test possibilities already reveals the reasons for the high motivation with which the well-known, unsolved test problem of nondestructive inspection of spot welds using ultrasonics has been taken up again for some years now.

**Literature**

[1] H. Polrolniczak
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