Process Control by Means of Non Destructive Ultrasonic Testing of Complex W-Cu Contact Components for Energy Transmission and Distribution

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Abstract

In cooperation with VOGT Ultrasonics GmbH a test stand for non destructive testing of electron beam welded WCu-components and blanks was conceived for testing under serial production conditions by means of the Ultrasonic Phased Array Technology.

The early, clear and easy recognition of the quality of the welding zone of WCu welded components with a user friendly Set-Up and software increases the process stability. A fundamental attribute of the ultrasonic test stand is the option to classify the component immediately and online according the defined quality criteria.

The challenge amongst high cycle times is to scan powder metallurgical produced WCu composite material components to evaluate the quality of the welding zone underneath. The WCu composite material is usually welded to a homogeneous copper or steel based material.

For several reasons it is not possible to send the ultrasonic beam through the homogeneous material in any case. Therefore the measurement has to be carried out through the inhomogeneous WCu part. Herewith the challenge is to avoid a significant ultra sound re- or deflection caused by the microstructure of a WCu composite showing big differences in density, weight and homogenity.

Keywords

Ultrasonic, phased array, tungsten copper composite, welding zone, electrical components, high voltage switch, non destructive testing

Introduction

Electric current at high voltages from 72.5 kV to 1200 kV is transmitted over great distances and distributed from 5 to 38 kV to final users such as households, industrial plants or transportation. Protecting the transmission networks and the distribution systems calls for technically reliable switchgear with long service life. They are subjected to extreme mechanical and thermal stresses. Temperatures of several thousand degrees Celsius occur on the surfaces for fractions of a second. Therefore a very high burn-off resistance, a low tendency to crack and a excellent thermal and electrical conductivity is required.

This challenging product profile can be fullfilled by manufacturing the sintering materials, but also the most modern joining and machining technologies, which are necessary for the high and medium voltage area.

The above described requirements to gain a reliable arcing contact system can be achieved by combining a powder metallurgically produced tungsten copper contact material (WCu) combined with a support material with sufficient mechanical strenght and very good electrical and thermal conductivity like Cu, steel etc [1, 2].

Principle of an arcing contact component for high voltages

Figure 1 shows a sketch how an arcing contact component system, consisting of a pin and a so called tulip, works.

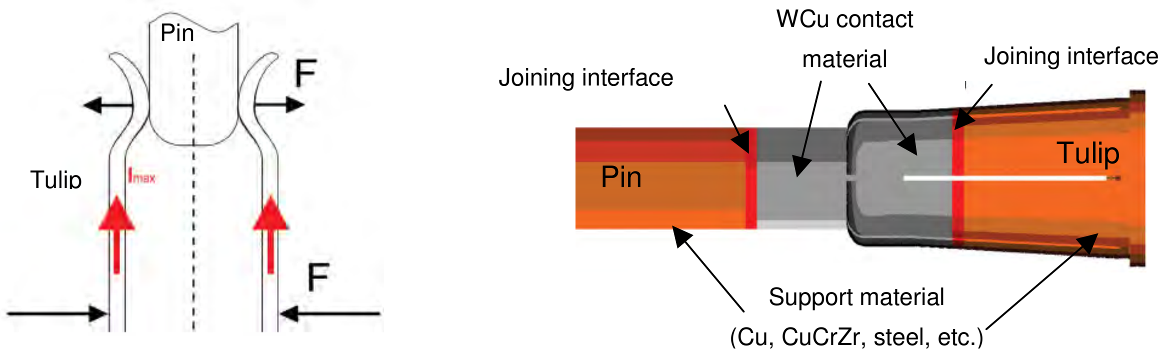

Fig. 1: Sketch of the function of an arcing contact system in closed, conductive position

It is shown that by means of the design of the tulip a minimum spring force has to be achieved to get an optimized and reliable contact to the pin surface. Therefore a maximum of energy transmission can be guaranteed and arcing between the two components can be avoided.

The following drawing (see Fig. 2) shows an example of such a tulip design, combining the required arcing resistance by means of WCu and the mechanical strength as well as good electrical and thermal conductivity by the mentioned support materials [3].

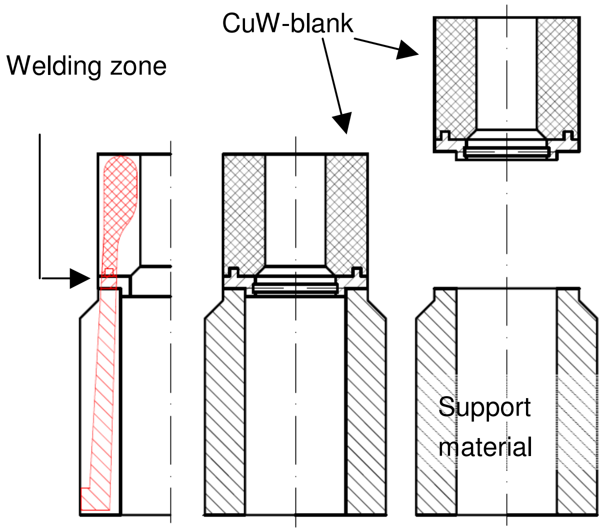

Fig. 2a: Drawing of an arcing contact tulip design:

Black: WCu and support material blanks

Red: Final design of the arcing contact Tulip

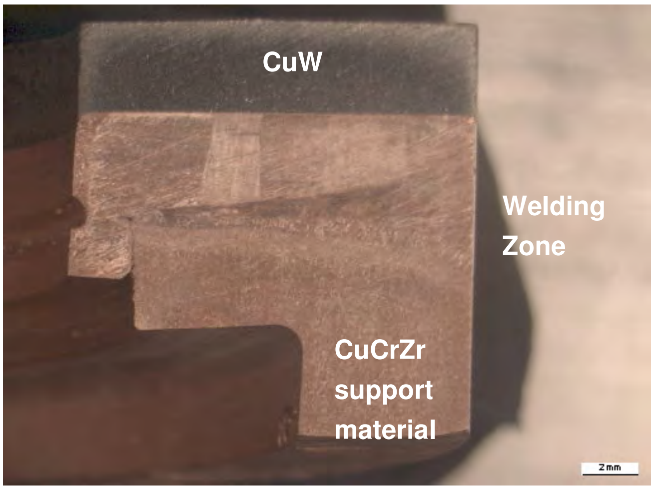

Fig. 2b: Cross section of the welded joint area of an electron beam welded tulip blank

The arcing resistant WCu part is preferably joined to the support material by means of electron beam welding. figure 2b shows a cross section of an already electron beam welded tulip blank. According the drawing, shown in figure 2a the tulip blank has to be machined to get the final arcing contact tulip design. It can be clearly seen that the welded area along the circumference decreases to thicknesses of a few millimeters.

To achieve the required spring force to gain an optimized contact to the Pin slits parallel to the longitudinal axes are usually intruduced and pretensioned. In figure 3 the arcing contact Tulip shows 8 slits parallel to the longitudinal axes.

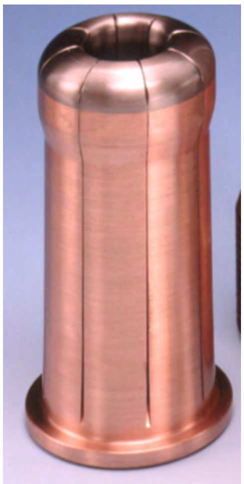

Fig. 3: Picture of a final arcing contact tulip - 8 tulip finger design

Therefore the welded areas are minimized significantly to small segments compared to the joint interface in the welded blank status as shown in Fig. 2a. As each tulip finger is under tension and an exchange of failed arcing contact components in the field causes enormous efforts and cost, a 100% non destructive quality control is inevitable.

WCu contact material

In the above described case of 90° welded arcing contacts an inhomogeneous WCu material has to be scanned through to the welding zone underneath. A cross section of a typical WCu microstructure gained by sintering and infiltrating with copper is shown in figure 4. Typical compositions are 60 to 80 wt.-% W and 20 to 40 wt.-% Cu.

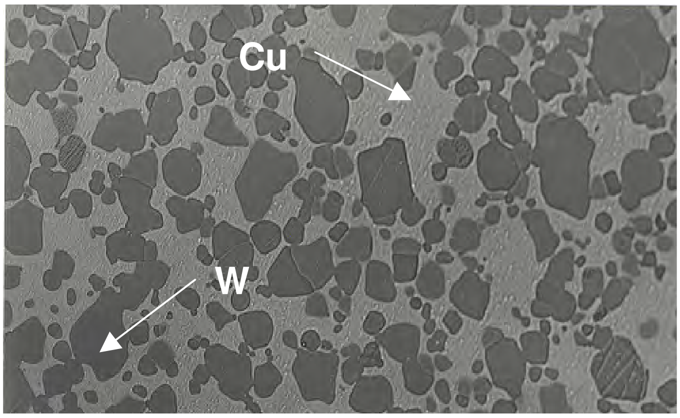

Fig. 4: Cross section of a typical WCu (80/20) microstructure

Tab. I: Properties of copper and tungsten [4]

Properties	Copper	Tungsten
Density [g/cm^3]	8.9	19.3
Electrical conductivity [MS/m]	59.77	17.70
Melting temperature [℃]	1083	3410

The inhomogeneous microstructure is caused by the very low solubility of W and Cu.

The combination of the excellent electrical conductivity of Cu together with the good arcing resistance and high melting temperature as well as high arcing resistance of W, see Table I, results in the usage of contact material for energy transmission up to voltages of 1200kV.

By means of a WCu 80/20 contact material with 80wt.-% W an electrical conductivity up to 30MS/m and more, depending on the W grain size and bulk density, can be achieved. Moreover the burn-off behaviour ranges from favourable to excellent also depends on the W grain size and the customized design [1, 3].

Ultrasonic Phased Array principle

In general the ultrasonic device transmits electrical pulses to the probe where these pulses are converted to ultrasound waves. After transmitting the waves the probe receives the reflected echos waves as well. All received waves are converted to electrical pulses again and are evaluated by the software. Phased Array probes are composed of several piezoelectric crystals that can transmit/receive independently at different times [5]. To focus or to steer the ultrasonic beam, time delays are applied to the elements to create constructive interference of the wavefronts. Due to this the ultrasonic beam can be steered within a range of angle and/or the energy can be focused at any depth in the test specimen (see Fig. 5).

Advantages of Phased Array

The advantages of Phased Array systems include the ability to perform electronic scanning of the ultrasonic beam, which can reduce inspection times by eliminating or reducing the need of moving the probe. One Phased Array probe can also replace an entire line up of conventional transducers. In conjunction with appropriate delay laws the Phased Array probe can reproduce the same acoustic beams achieved with numerous conventional probes, while also providing greater functionality.

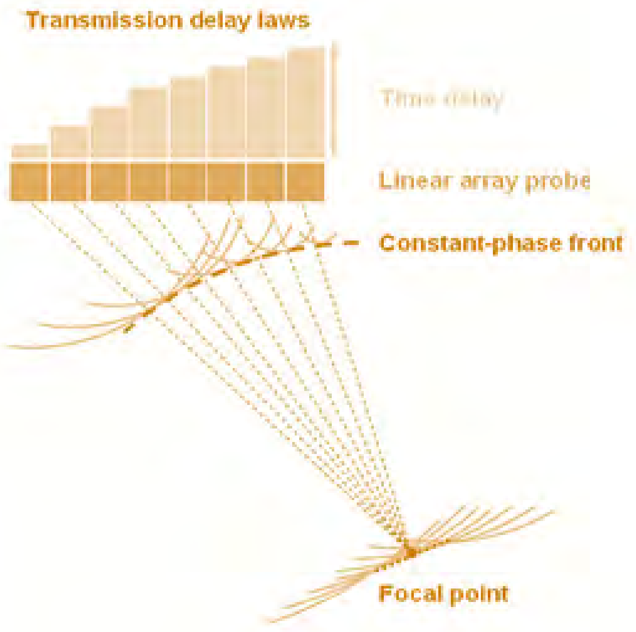

Fig. 5: Principle of beam steering and focussing

Phased array ultrasonic test stand

The task of the ultrasonic scanning system is to test the weld of the tulip within the production cycle with an offline system. Thereby it detects non connected areas in the weld seam, measures the sizes and classifies the tulips in “good” or “bad” according to given guidelines. The inspection is done by immersion technique.

Depending on the type of tulip there are two possible probe positions to insert the ultrasonic beam perpendicular to the welding. Inspecting the 45 degree weld requires a probe position along the body. The 90 degree weld needs to be inspected from above (see figure 6).

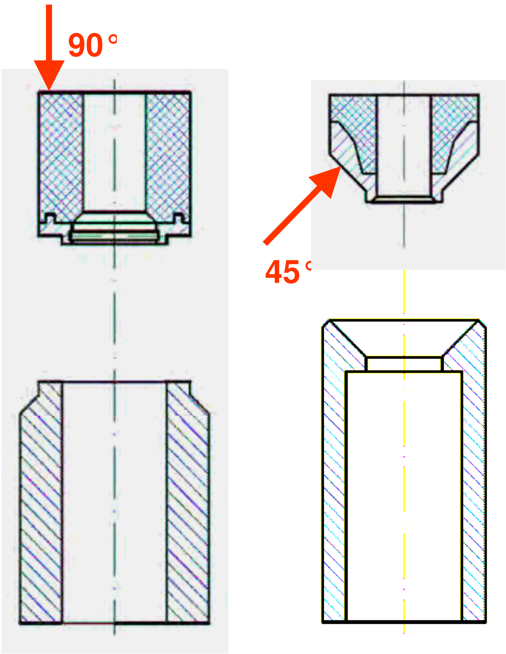

Fig. 6: Cross section of a typical tulip and marked position of Ultrasound beam direction.

System Layout

The inspection object is manually placed in a special holder inside the water tank by the operator. The holder itself is mounted on a turn table. Initially, the probe has to be aligned to the tulip surface. Therefore the system uses a X/Z axis linear motion unit for a rough and an A/B- axis manipulator for a fine adjustment. This adjustment procedure has to be done once only per batch size. After finishing the set up the inspection can be started.

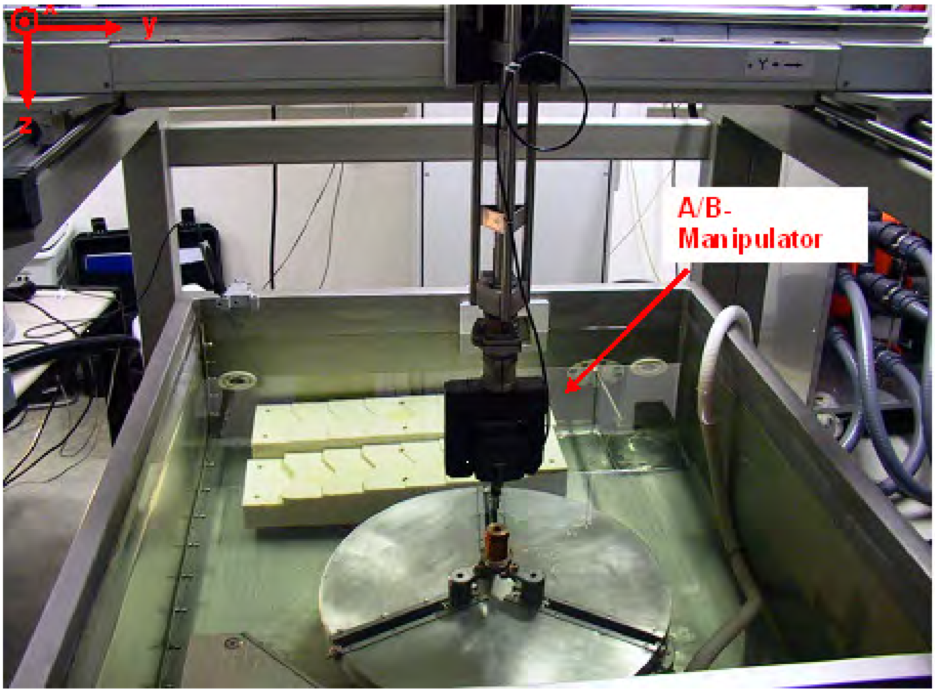

Fig. 7: conventional immersion technique system

Thanks to the Phased Array Technique, maximum two rotations are needed to inspect the whole weld depending on the tulip type. Adjacent to the inspection the final result is displayed on a screen. According to this the operator is separating the tulips into “good” and “bad” parts.

The mechanical design of the Phased Array inspection system, mainly all moving parts and the water tank, will be realised on the basis of a multi axis scanning system but only in much smaller dimensions. To get a first impression an immersion system is shown as an example in figure 7.

Evaluation

The whole scan area which has to be inspected is evenly divided into sections. Each section is checked in terms of defect size (reflectivity) and maximum acceptable defective area for a certain threshold value. The evaluation software is starting adjacent after finishing the data acquisition.

Example for a Phased Array tested tulip

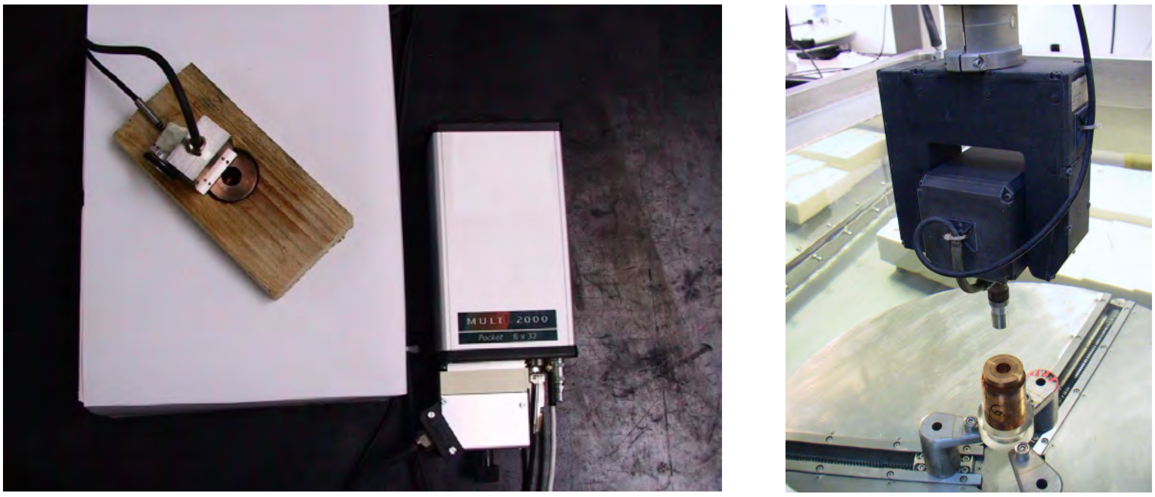

Fig. 8: 90° inspection using contact testing technique with a linear Phased Array probe (l.) and using immersion technique with a conventional probe (r.)

For demonstrating the Phased Array technique, two C-Scans (conventional probe in immersion and Phased Array probe, see fig. 8) of a reference block were recorded and compared under consideration of existing differences of both techniques (e.g. C-Scan views). The chosen reference block is normally used for the system calibration and check up for each 90° inspection of Plansee tulips. Therefore it contains two precise vertical bores in the welded area, one 2 mm and one 3 mm flat bottom hole (FBH). These bores are displayed in the scan images.

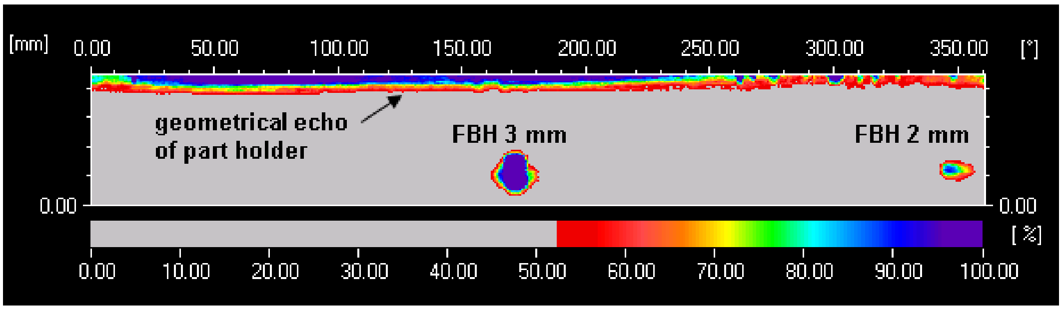

Fig. 9: C-Scan image of reference block recorded with ScanMasters LS 100 immersion system

Figure 10 (right picture) shows the C-Scan image recorded with a Phased Array system, the result of the conventional immersion inspection is shown in figure 9 as a linear illustration and in figure 10 (left picture) as a round illustration. Comparing both C-Scan images it is to be seen clearly the same results but the way of recording is different. Using Phased Array technique the whole data acquisition and scan imaging lasts no longer than 10 seconds, while the conventional inspection method needs about 2 minutes. Due to the limited capability of the chosen probe in this case the resolution is slightly worse compared to the immersion probe, but it is no effort to get the same resolution like in figure 9 by using another probe.

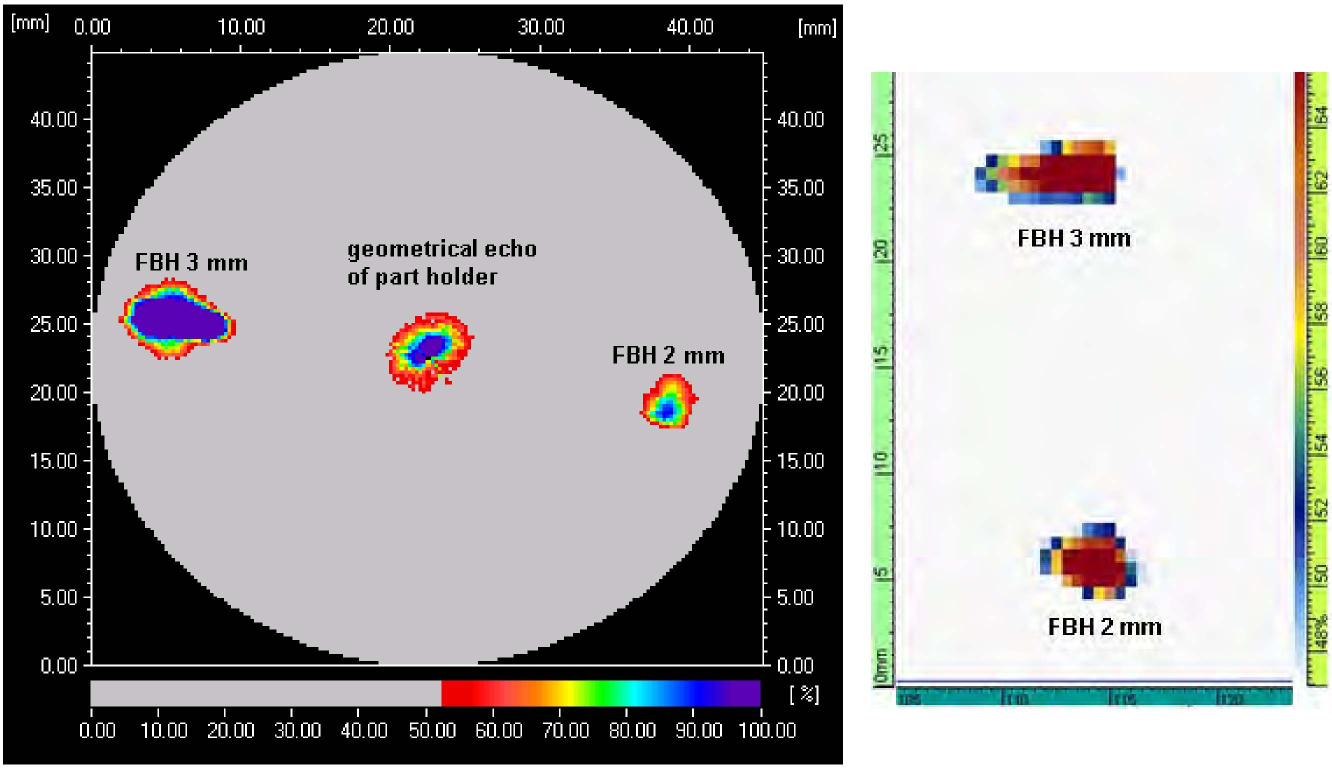

Fig. 10: Round C-Scan image of reference block recorded with LS system (left) and image recorded with Phased Array hand device (right)

Conclusions

To guarantee a sufficient welding joint in each single welded segment of the final Tulip design the non destructive ultrasonic scanning seems to be an economically and environmentally reasonable method to qualify welding interfaces with the necessary accuracy for series production. It has to be pointed out that ultrasonic scanning is a well established test method for homogeneous and metallic materials, like steel or other alloys and materials. In the above described case of 90° welded arcing contacts a inhomogeneous WCu material has to be scanned through to the welding zone underneath.

By means of the phased array technique and the test stand concept described in this work it is possible to get scanning results with a reasonable resolution and required cycle time.

The achieveable resolution allows to apply the compulsory quality criteria to secure a sufficient welding joint even for very small joined interfaces. Through the visualisation of the analysis results it is possible to localize failures in the welding joint interface clearly. Therefore a selective rework can be carried out. A reduction of rejects as well as a proofed and satisfactory welding joint quality can be guaranteed.

By means of the achievable high cycle time the requirement of a 100% and just in time quality control is fulfilled.

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