

3D Ultrasound Imaging of Flaws, Electronics and Spot Welds

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Abstract

We have developed a 3D imaging flaw detection system using commercially available ultrasonic sensors and equipments. The scanning was carried out using an ISEL step motors and the path is in 2D in the first version of the equipment with resolution 1mm. The resolution of that system was better than 3mm SDH but lately it was improved using focused head down to 1mm SDH. In the next generation we used better resolution in movement down to steps of 0.1 mm and we can distinguish surface notches less than 0.1mm. The most important part of the 3D system is the 3D picture produced by computer code in LABVIEW allowing rotating of the final picture of flaws and producing real tomographic view of flaw in the metal. Comparing our system with commercially available similar systems it is surprisingly cheap and reliable. The system was tested first on specially developed etalons, containing holes and notches. Then it was used to find holes and lunkers in molded electronic parts in automotive industry, where we can present different layers of electronics. Finally we are heading to develop an application of that device on spot welds slicing the nugget with better than 0.2mm layers.

Keywords: Scanning acoustic (ultrasonic) microscope, immersion, mechatronics, flaw detection, welding,

1. Introduction

A **scanning acoustic microscope (SAM)** is a device which uses focused sound to investigate, measure, or imagine an object having parts with different acoustic impedance. The first scanning acoustic microscope was developed in 1974 by Lemons and Quate [1]. Scanning acoustic microscopy works by directing focused sound from a transducer at a small point on a target object. The reflected sound is sensed by the same of the receiver ultrasound probe. From the reflections using the general knowledge in ultrasound technique corresponding picture is produced. It has found its application in biology and medicine today but it is much rarely used in small sized flaw investigation in industry.

Industrial use of scanning, immersion type ultrasound techniques are getting widespread in the last decade [2]. However, they are used mainly for relatively large object. It is also true that they are not very cheap.

Our original development task was initiated by the automotive industry, where electronics are widely used. They are encapsulated into a closed plastic box or, more frequently, circuits are casted in resin. The original task was to detect air bubbles in resin. We shall see that it was possible to reach even better resolution using high frequency ultrasonic probes. Components and principle of our SAM are presented in Sections 2 and 3. It is also shown in Section 4.1 that we can reach resolution better than 0.1 mm.

Once we could reach resolution better than 100 microns, it became interesting to use it not only for electronics in resin but also for small size spot welds. Results are shown in the fourth section. To understand how our relatively cheap SAM works the reader must go through the first three sections. It is worth to pay also attention to moving mechanics, since it makes the resolution better than expected.

2. Description of the hardware

The SAM system consists of a glass pool where the tested sample can be positioned under the water (Fig. 1). A movable bridge with an ultrasonic probe fixation is positioned above the pool. The position of the fixation can be controlled with precision of 10 microns using a step motor from ISEL [3]. It is driven today by ISEL PLC based electronics, but soon we intend to convert it to LABVIEW [4] control. Today we are using V376-SU focused immersion probe produced by Olympus [5], which is attached to Epoch 1000-i, where normal A-scans are produced at every steps where motor stops.

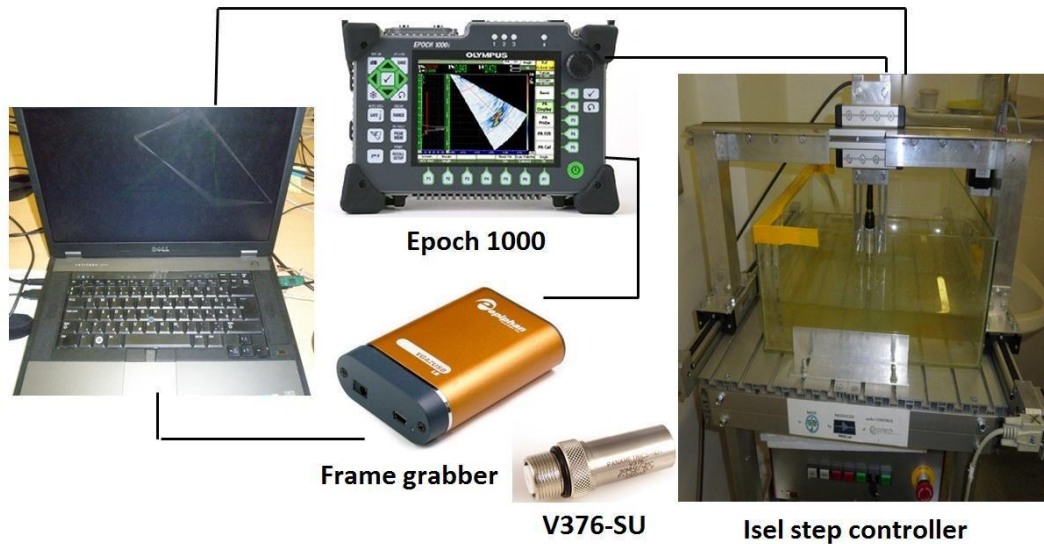


Fig.1. Components of the SAM system

Unfortunately, most of the available ultrasound measuring systems do not provide digital picture outlets for A-scan; therefore we also had to use the VGA outlet and an analog-digital converter to send the A-scan picture to the computer where the data processing took place.

3. Processing ultrasonic A-scan data in the computer

It is well known, that A-scan (Fig. 2) contains information on the time of arrival the reflected sound. Each peak in the A-scan appears at horizontal scale according to the transit time and in magnitude according to the intensity of the signal, which depends mainly on the size and orientation of the reflector. We do not filter out even small peaks as it is proposed by many standards, since we take samples in a raster where the size of the raster may vary from 10 microns to 1 mm. In the computer a 3D array is building up (see Fig.2).

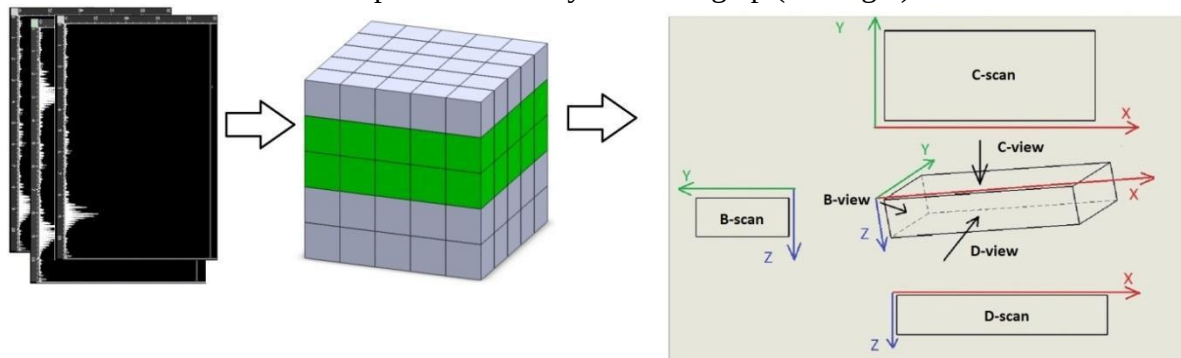


Fig.2. Typical A-Scans transferred via an array to B-scan, C-scan and D-scan

Once the scanning is over, we have a 3D array, and we can use the wide variety of image processing software to process the images (Fig.2). Each element of the array contains information about the position in 3D and intensity of the reflection from that position. Filtering, averaging and many other tricks may help to improve the visibility. We produce B-scan, C-scan and D-scan and we present them to the user on a user friendly display (Fig. 3), but the most effective helper for the user is the 3D presentation (Fig. 4) which can be rotated manually thus finding those spots inside the object under investigation.

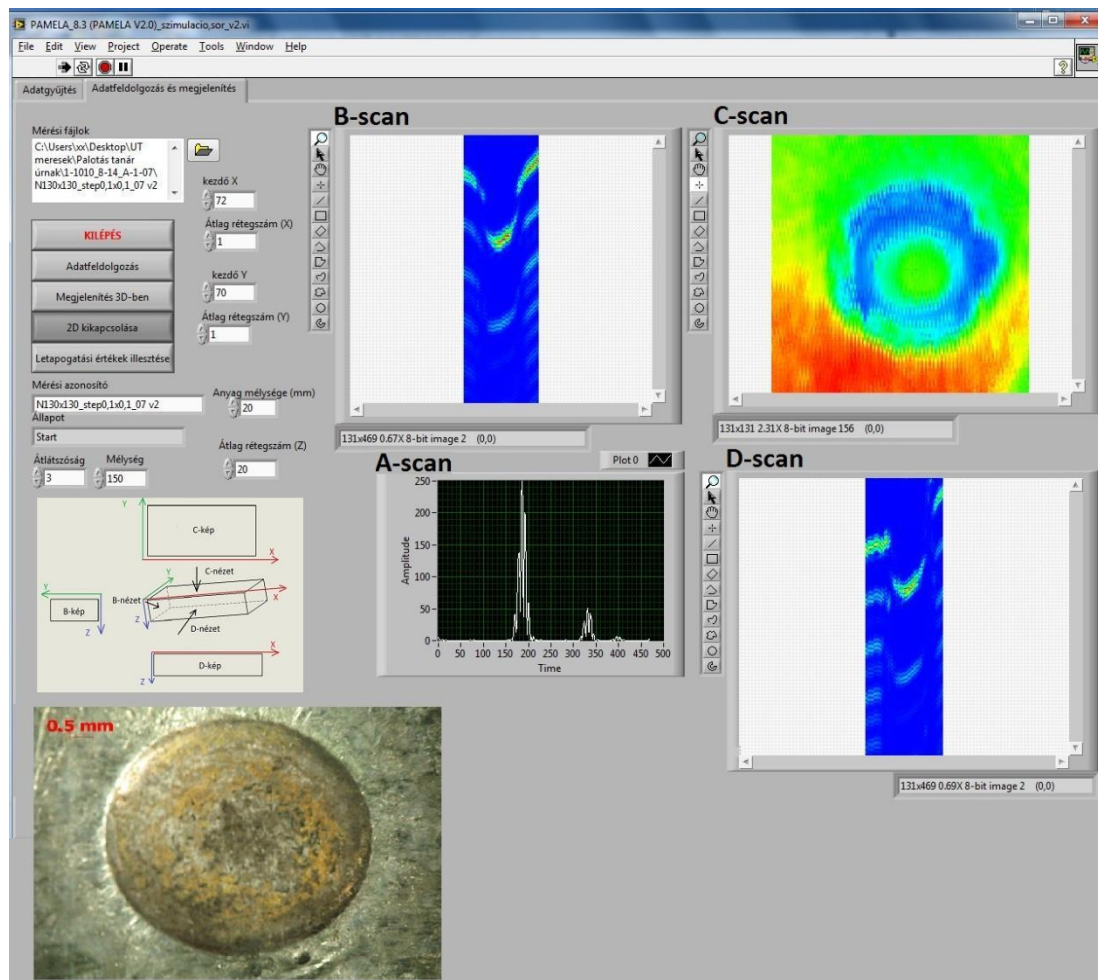


Figure 3. User display

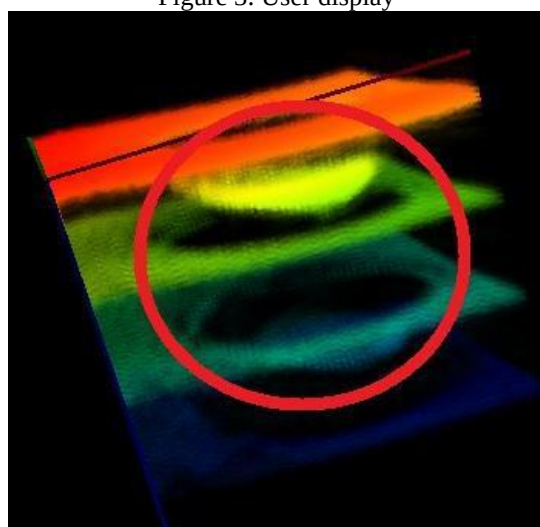


Figure 4. 3D rotatable presentation of the array

4. Successful applications

4.1 Presenting resolution examining a spot weld

Spot welding is a widely used joining process in automotive industry. Recently new steels (TRIP, TWIN etc.) appeared in their production line. It is rather important to examine the quality of the spot welds depending on the welding parameters. For fast checking ready-made spot checkers can be found [6]. However, it is just a fast insight to the welding but without details. Examining a spot weld here (Fig. 5) we present the resolution of our method.

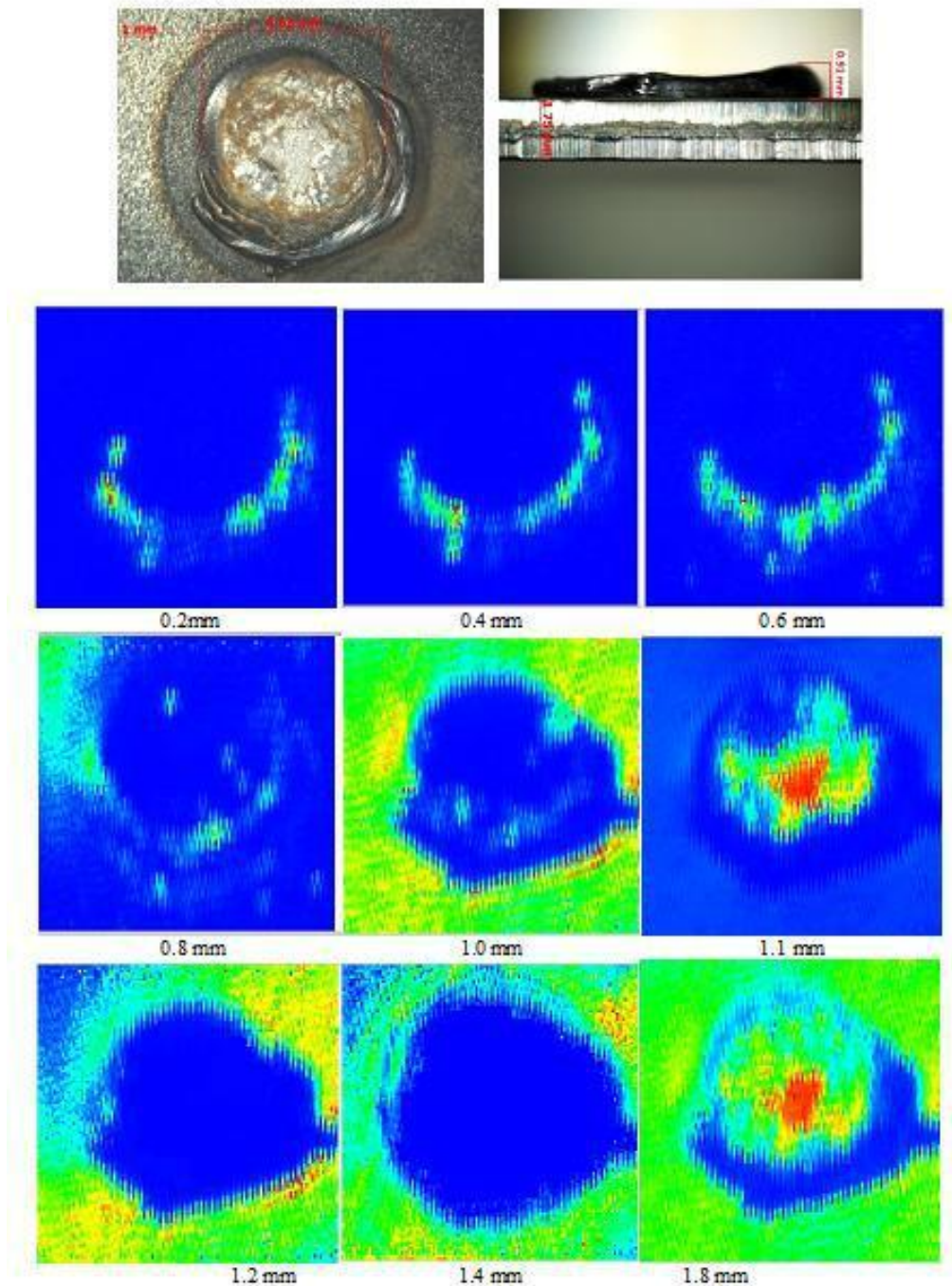


Figure 5. Peeling the weld

This was not an acceptable quality spot weld; since it had a crown. But this made us possible to demonstrate on how effective our slicing is. It can be seen, that we were able to slice (to peel) various layers of welded joint with resolution of at least 0.06 mm. First the crown of the “low quality” weld can be seen on the uppermost layers (0.2-0.4-0.6 mm), and then we were going deeper, until the level of the metal sheet surrounding the spot weld (1.0mm). It is well seen that the nugget upper level is deeper than the outer metal sheet level (1.2mm). However around the crown and in the crown there are no reflections (blue). At 1.2mm level we have the backwall echo of the upper sheet. Finally, we reach the backwall of the spot weld nugget at 1.8mm.

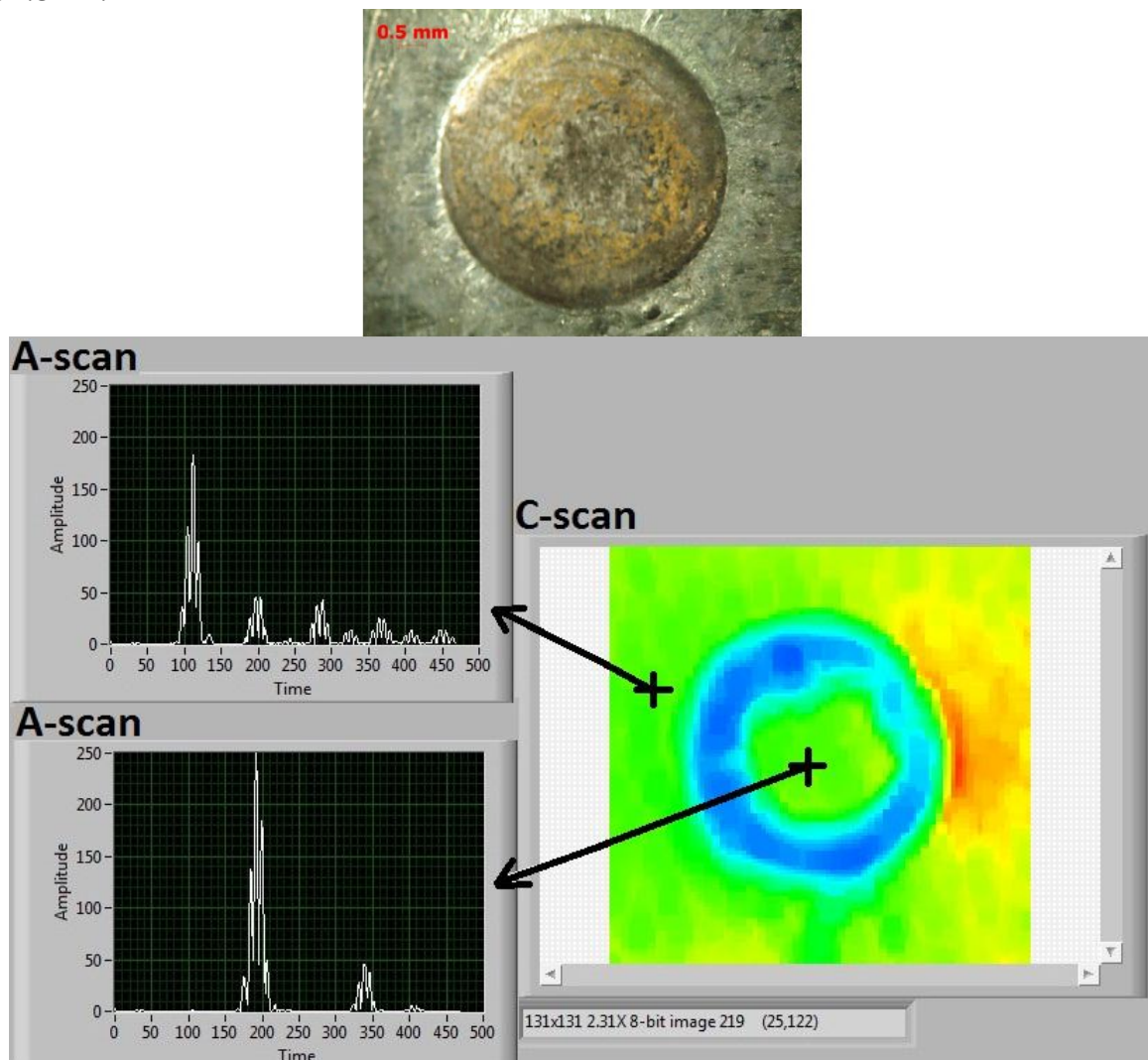


Figure 6. Photo and ultrasonic A-scan and C-scan result of a good spot weld

An example of the user display is presented on Fig.6, where a much better spot weld nugget is shown. On the right hand side one can see the unusual C-scan with two spots marked by “+”. Corresponding A-scans can be seen on the left hand side. From those it is obvious that in the middle of the nugget we had double thickness, thus the fusion in the spot weld was good.

4.2. Slicing a good spot weld

On Fig. 7 one can follow slicing by ultrasound SAM a good spot weld. It was not possible to put the spot weld absolutely horizontally under SAM. Since it is tilted the upper surface of the upper metal plate can be seen on three different depths (Fig. 7/b). Similarly the surface of the

nugget is shown also on three small pictures (Fig. 7/c). It was deeper than the upper surface of the plate. We have the backwall reflection of the upper plate on Fig. 7/d.

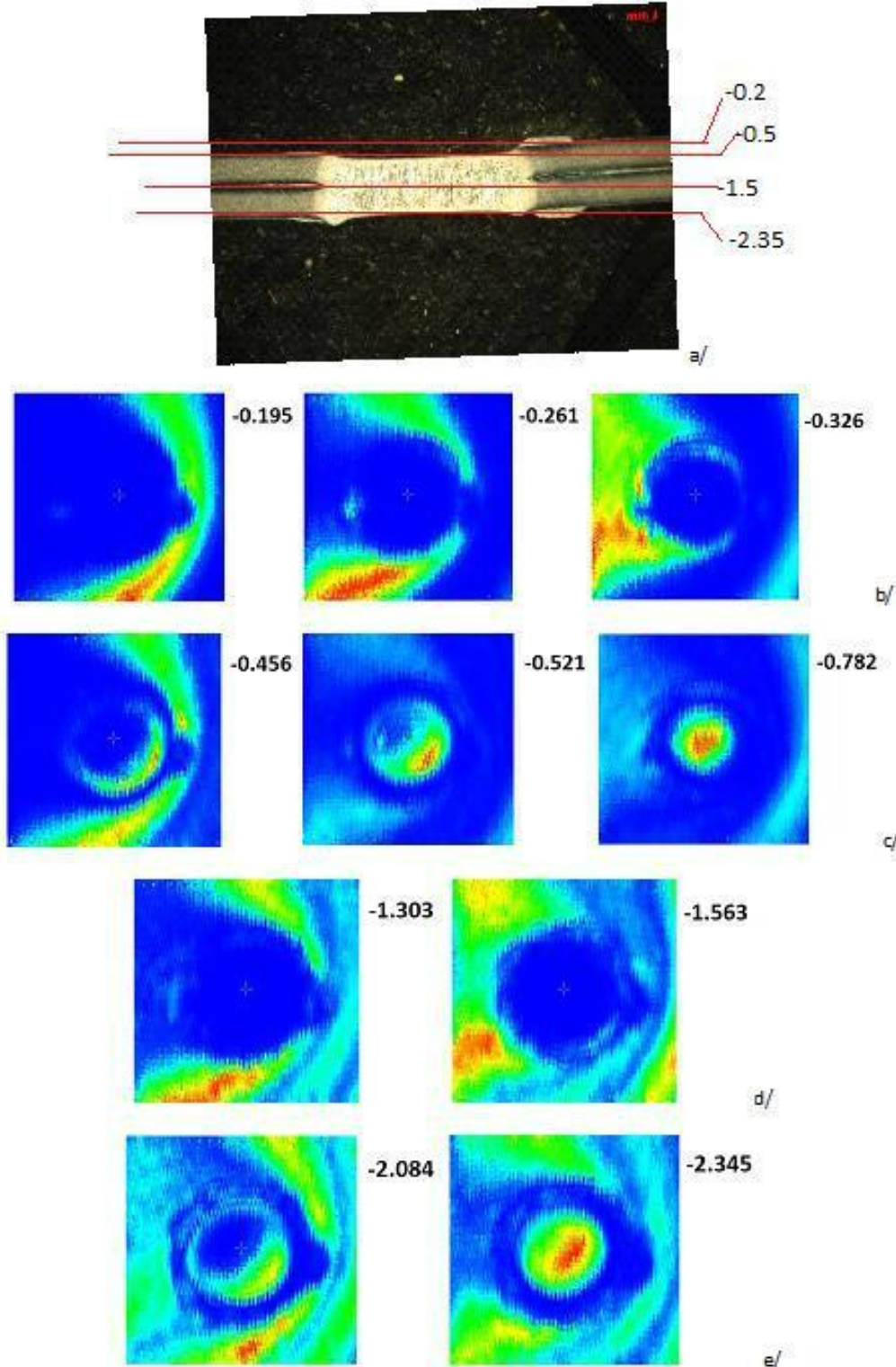


Figure 7. Cross section the spot weld (a), and its sliced ultrasound reflection from different depth (b-e) /numbers mm/

Remarkable, that there is no reflection at that level from the nugget, since the fusion was perfect. The reflection of the backwall of the nugget appears at the -2.35mm level (Fig.7e), which proves once more the proper quality of the spot weld.

4.3 Slicing a bad spot weld

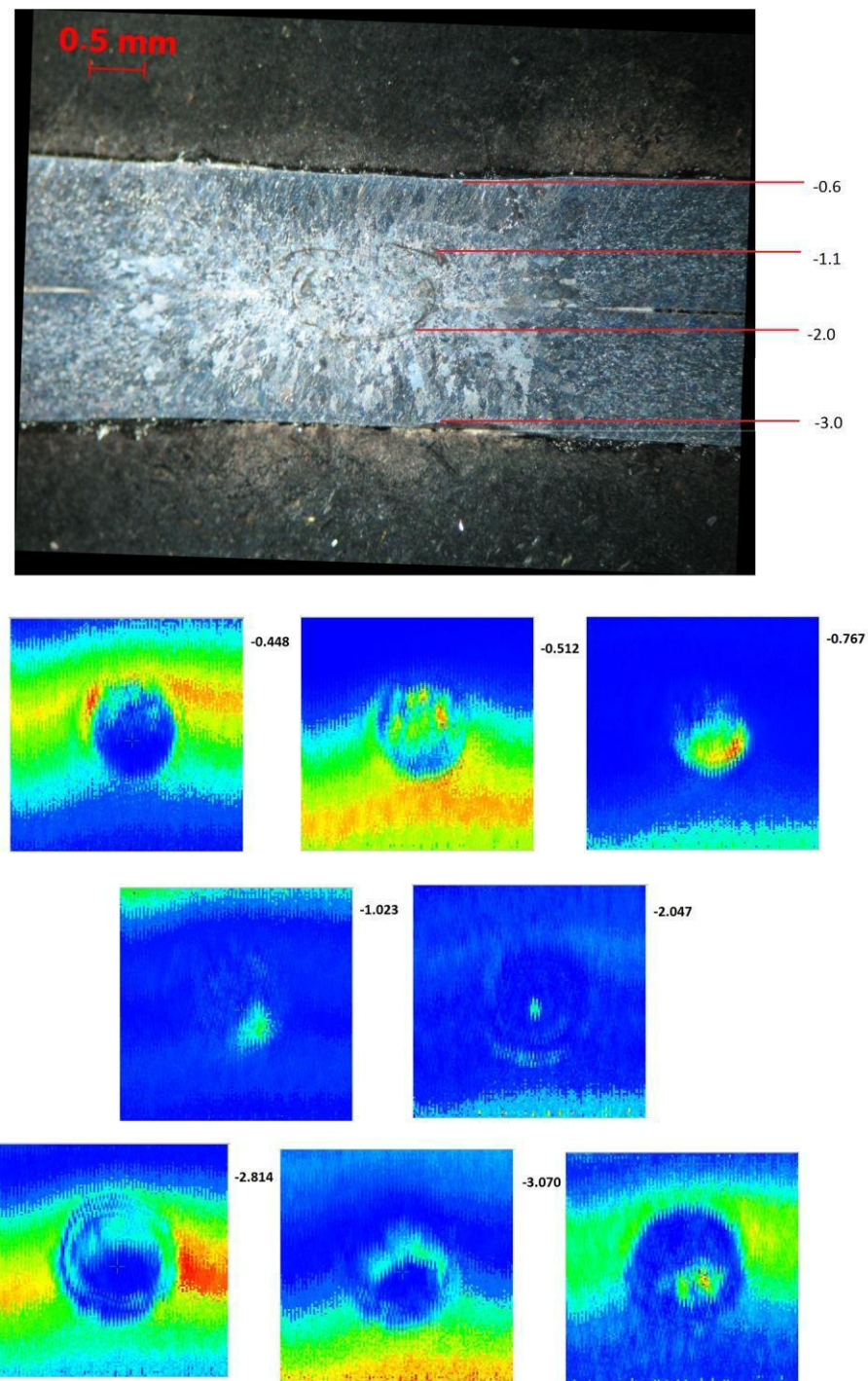


Figure 8. Microphoto of the embedded and cut spot weld with sliced ultrasound reflections

In case of a bad spot weld we got reflection at those elevations where ultrasound reflectors could be found. After careful preparation of the spot weld following standard procedure for preparation of metallographic specimens [7] a microphoto had been made (see on Fig.8 upward). During ultrasound measurement the metal sheets were tilted for 2 degree (this is demonstrated on photo). In the first row one can see the front reflection from sheet (first two) and from the nugget (third one in the first row). Middle row shows two reflectors of the upper and lower end of the nugget. In the third row we have the backwall reflections.

4.4 Slicing electronics

Another application of SAM can be checking the electronics casted in resin. As we told in the introduction, this was the original aim when we started the development. Electronics casted in resin are widely used in automotive industry, since in that case there is no influence of any wettings or vibration. However, it is important that the resin would be monolith. A typical error of casting can be if there is a bubble in resin. It is the most dangerous if it is near to the edge. But the electronics inside is also an issue.

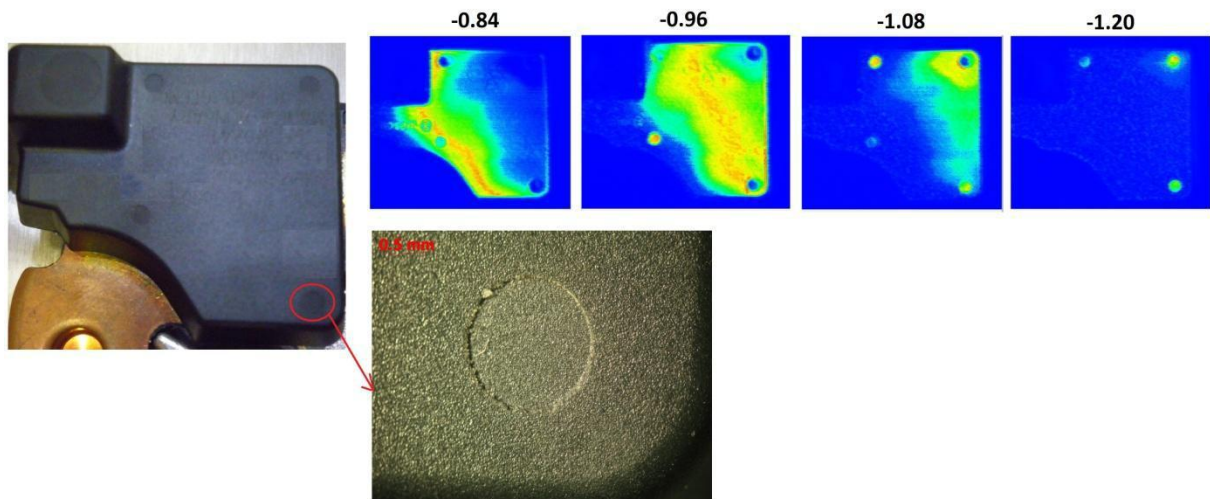


Figure 9. Photo of upper surface of resin and different levels of slicing by ultrasound. We could even measure the depth of round pressed closing (in mm)

Another proof of quality of our exciting slicing technology is seen on Fig. 9. The depth of the round impression on the surface of the resin is smaller than 0.1mm. Still it is clearly distinguishable on the SAM slicing pictures in spite the fact that it is hard to see on normal photos.

But ultrasound can see not only the surface but it can move through the resin to electronic details (Fig. 10).

To understand the slicing SAM pictures on Fig. 10 we show on normal photos the surface of resin, and the inner part of electronics casted inside the resin in the upper row of Fig. 10. Relying on those photos it is easy to understand what we see on slices.

In the second row the first picture is the surface of the resin (cf. Fig.9). Going deeper we see few snowflake pictures. Those are small bubbles in resin, but they do not cause any problem for functionality, except of large round shaped bubble on elevations of -1.92 and -3.48 (mm). They deserve further attention.

It is worth to call the attention to the two sharp reflections on elevation of -3.00mm. Comparing with photo in the right upper corner they are clearly those two electronics element which were popping out maximally from the surface mounted electronics. On the next elevation (-3.48mm) the next electronics surface can be seen. It is hard to notice the difference between their top levels on photo. Please do not forget, that all SAM pictures were made through the resin! The surface of the biggest integrated circuit can be seen on picture from elevation -4.56mm. It is the resin of the IC. Going deeper we can see a metal reflection inside the IC at the elevation of -5.16 mm that is most probably the chip itself. On the next elevation

at -5.28, one can see the bottom of IC with the wire connection to the surface mounted plate (-5.28-5.52mm). One cannot wish better resolution.

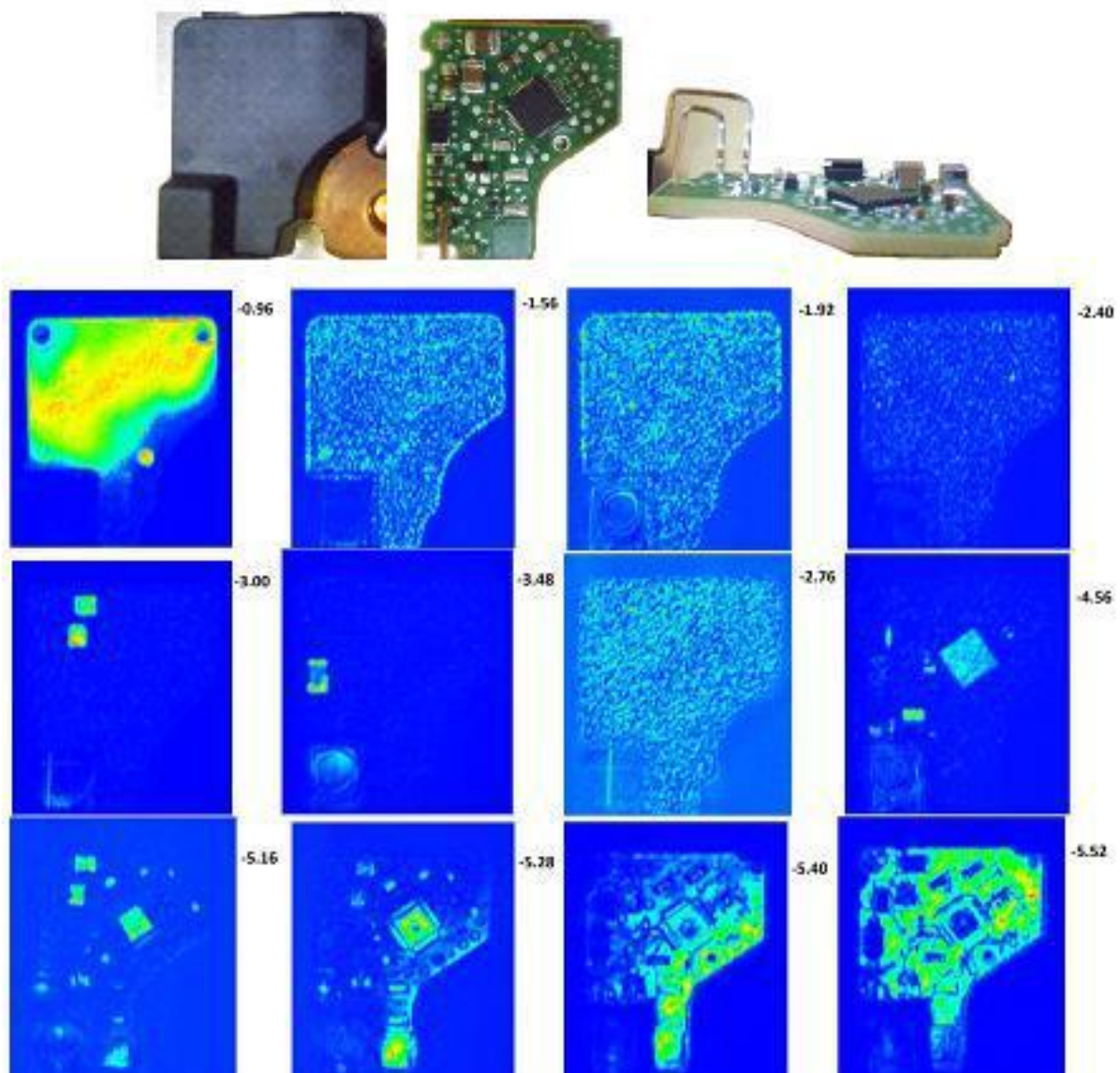


Figure 10. Photos of electronic (upper row) and slicing with ultrasound for different depth (numbers are in mm)

5. Conclusions and outlook

We have developed a new, relatively cheap and goal oriented SAM with immersion type focused ultrasonic probe. Coupling ultrasonic reflections with automatic scanning with a minimum step of 50 microns, we produced a large array of intensity versus space corresponding to the magnitudes of reflection. This array was used via computer image technique to construct and present B-scan, C-scan, D-scan and rotating 3D images, or slicing horizontally the objects with an accuracy of better than 100 micron. Thus we can slice the object with resolution of 0.1 mm finding reflecting surfaces in the given depth.

In case of a spot weld it was possible to notice the smallest deviation from the flatness and what is more important to find if the weld quality namely if the fusion at the surface of the two metal sheets was good or bad.

In case of contemporary electronics casted in resin it was possible to find either bubbles in resin or even mismatches in printed boards if they are larger than 0.1 mm.

It is very promising that the 3D array with 10 micron resolution in perpendicular direction contain many redundancy opening the way for further data processing improving the resolution even in the third direction as well. This opened the way for slicing. We believe this is a very good new tool for practical use of the ultrasound microscopy. It is not always easy to understand A-scan or B-scan or C-scan pictures but it is easy to understand the sliced pictures. It was especially useful for spot weld, where one can found that level where the fusion must take place. We have slicing accuracy today only 0.06 mm, but we are expecting further improvement using 50MHz probe, a better moving mechanism and new filtering methods. An advantage of our measuring set, that it can be easily fitted to the given goal. Here we presented only results in examining spot welds and electronics but new tasks are ahead.

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