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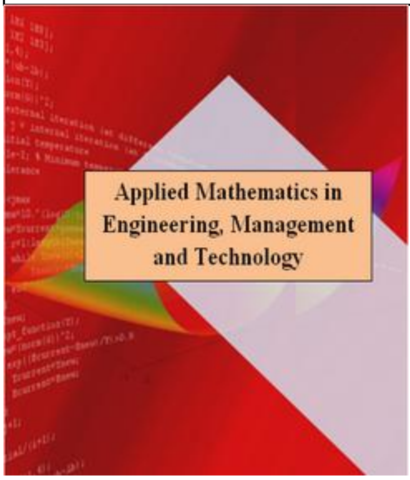
# Study of environmental problems caused by non-destructive testing, focusing on the nature of the probe

**Jahan Taghizadeh[*1], Saeid Moshtaghpoor[2], Amir Heydari[3]**
[1]Assis. Prof., Mechanical Engineering Faculty, Qom University of Technology, Qom, Iran
Taghizadeh@qut.ac.ir
[2]MS.c Student in Manufacturing Engineering Parsian Institute of Higher Education, Qazvin, Iran
[3]MS.c Student in Manufacturing Engineering Parsian Institute of Higher Education, Qazvin, Iran




**Abstract:**

Ultrasonic sensors (also known as transceivers when they both send and receive, but more generally called transducers) work on a principle similar radar or sonar which evaluate attributes of a target by interpreting the echoes from radio or sound waves respectively. Ultrasonic sensors generate high frequency sound waves and evaluate the echo which is received back by the sensor. Sensors calculate the time interval between sending the signal and receiving the echo to determine the distance to an object. This technology can be used for measuring wind speed and direction (anemometer), tank or channel level, and speed through air or water. For measuring speed or direction a device uses multiple detectors and calculates the speed from the relative distances to particulates in the air or water. To measure tank or channel level, the sensor measures the distance to the surface of the fluid. Further applications include: humidifiers, sonar, medical ultrasonography, burglar alarms and non destructive testing. Systems typically use a transducer which generates sound waves in the ultrasonic range, above 18,000 Hz, by turning electrical energy into sound, then upon receiving the echo turn the sound waves into electrical energy which can be measured and displayed. The technology is limited by the shapes of surfaces and the density or consistency of the material. Foam, in particular, can distort surface level readings.

**Keywords:** Probe, Transducer, Ultrasonic, Non destructive testing, friendly

## 1- Introduction

An ultrasonic transducer is a device that converts energy into ultrasound, or sound waves above the normal range of human hearing [1]. While technically a dog whistle is an ultrasonic transducer that converts mechanical energy in the form of air pressure into ultrasonic sound waves, the term is more apt to be used to refer to piezoelectric transducers or capacitive transducers that convert electrical energy into sound. Piezoelectric crystals have the property of changing size when a voltage is applied, thus applying an alternating current across them causes them to oscillate at very high frequencies, thus producing very high frequency sound waves [2]. The location at which a transducer focuses the sound can be determined by the active transducer area and shape, the ultrasound frequency, and the sound velocity of the propagation medium. The example shows the sound fields of an unfocused and a focusing ultrasonic transducer in water. Since piezoelectric crystals generate a voltage when force is applied to them, the same crystal can be used as an ultrasonic detector. Some systems use separate transmitter and receiver components while others combine both in a single piezoelectric transceiver. Non-piezoelectric principles are also used in construction of ultrasound transmitters. Magnetostrictive materials slightly change size when exposed to a magnetic field; such materials can be used to make transducers[3].. A capacitor microphone uses a thin plate which moves in response to ultrasound waves; changes in the electric field around the plate convert sound signals to electric currents, which can be amplified.

### 1-1- Use in medicine

Medical ultrasonic probes come in a variety of different shapes and sizes for use in making pictures of different parts of the body. The transducer may be passed over the surface of the body or inserted into a body opening. Clinicians who perform ultrasound-guided procedures often use a probe positioning system to hold the ultrasonic transducer. Air detection sensors are used in various roles. Non-invasive air detection capabilities in the most critical applications where the safety of a patient is mandatory. Many of the variables, which can affect performance of amplitude or continuous wave based sensing systems, are eliminated or greatly reduced, thus yielding accurate and repeatable detection. The principle behind the technology is that the transmit signal consists of short bursts of ultrasonic energy. After each burst, the electronics looks for a return signal within a small window of time corresponding to the time it takes for the energy to pass through the vessel. Only signals received during this period will qualify for additional signal processing[4].

**1-2- Use in industry**

Ultrasonic sensors are used to detect movement of targets and to measure the distance to targets in many automated factories and process plants. Sensors with an on or off digital output are available for detecting the movement of objects, and sensors with an analog output which varies proportionally to the sensor to target separation distance are commercially available. They can be used to sense the edge of material as part of a web guiding system. Ultrasonic sensors are gaining popularity in a number of uses including ultrasonic people detection and assisting in autonomous UAV[1]navigation. Because ultrasonic sensors use sound rather than light for detection, they work in applications where photoelectric sensors may not. Ultrasonic's are a great solution for clear object detection, clear label detection and for liquid level measurement, applications that photo electrics struggle with because of target translucence. Target color and/or reflectivity don't affect ultrasonic sensors which can operate reliably in high-glare environments. Other types of transducers are used in commercially available ultrasonic cleaning devices. An ultrasonic transducer is affixed to a stainless steel pan which is filled with a solvent (frequently water) and a square wave is applied to it, imparting vibrational energy on the liquid[5]. Nowadays ultrasonic sensors are widely used in automotive applications for park assist technology.

**2- General Notes**

To perform the test, select one of the important points of the probe is used to a great extent the results of this choice is affected. Here, we try to provide full guidance for decision making regarding the selection of the probe.

**2-1-** Probe selection for every application, especially in the welded parts should be done by considering the following cases[6]:

- Diameter and thickness of the coupling
- Geometry Connection
- Welding conditions
- Metallurgical structure of the weld and base metal
- Type, position and orientation of possible defects in the weld

Probe selection is also dependent on the location and part of the probe for early detection and evaluation of the pilot to detect defects or faults in specifications and dimensions are used. A bilateral agreement between the tester and probe selection employer is generally based on the factors described in sections 2.2 to 2.7 occurs.

**2-2- Frequency:** Frequency is the number of occurrences of a repeating event per unit time. It is also referred to as temporal frequency, which emphasizes the contrast to spatial frequency and angular frequency. The period is the duration of one cycle in a repeating event, so the period is the reciprocal of the frequency. For example, if a newborn baby's heart beats at a frequency of 120 times a minute, its period – the interval between beats – is half a second (60 seconds (i.e. a minute) divided by 120 beats). In some fields, especially where frequency-domain

[1] Unmanned Aerial Vehicle *(*UAV*)*

analysis is used, the concept of frequency is applied only to sinusoidal phenomena, since in linear systems more complex periodic and no periodic phenomena are most easily analyzed in terms of sums of sinusoids of different frequencies.
For cyclical processes, such as rotation, oscillations, or waves, frequency is defined as a number of cycles per unit time. In physics and engineering disciplines, such as optics, acoustics, and radio, frequency is usually denoted by a Latin letter *f* or by the Greek letter ν. Note, the related concept, angular frequency, is usually denoted by the Greek letter, which uses the SI unit radians per second ($\frac{rad}{\sec}$). For counts per unit of time, the SI unit for frequency is hertz (Hz), named after the German physicist Heinrich Hertz; 1 Hz means that an event repeats once per second. A previous name for this unit was cycles per second ($cps$).
A traditional unit of measure used with rotating mechanical devices is revolutions per minute, abbreviated r/min or rpm. 60 r/min equals one hertz.
The period, usually denoted by *T*, is the duration of one cycle, and is the reciprocal of the frequency $f$: $T = \frac{1}{f}$ ,The SI unit for period is the second.
Given the following frequency representation of the probe on the probe affect.

**2-2-1- Resolution:** Increase in the ultrasonic frequency, wavelength will reduce the divergence angle and wavelength for a specific transducer size, the effect of increasing the frequency will decrease. According to improving the resolution of these cases, the accuracy of measurement in the direction perpendicular to the axis along the axis of the wave and the wave increases.

**2-2-2- Depreciation:** High frequency waves, in particular the way around the base metal and weld metal, are amortized very quickly. It should be noted that this effect is greater in the metallurgical structure of the material long distances and rough waves (coarse ones) is important. For practical purposes probe angular shear wave (4 - 6 MHz) can be used for ranges up to 200 mm in materials with natural grain structure, can be used. But the larger ranges or dissipation materials, high frequency probe should be approximately 2-3 MHz Probe of the pressure wave can be used in most large range.

**2-2-3- Coupling:** Low-frequency probe is not very dependent on the surface roughness. While the probe with a frequency of 4 to 6MHz than quality levels are sensitive and if the operator to identify the defect by echo height, the surface smoothness is committed to diversity, it is recommended to use the low frequency probe.

**2-2-4- Minimum defect size:** Size frequency can be extracted from the minimum defect size (Typically Client needs it.). It goes back at least to the point of discontinuity that can be detected is about half the ultrasonic wavelength. Of course, this is true when the noise is
not excessive.

**2-2-5- Reflector(defect) properties:** Because a low frequency probe, a broad wave in the far field than the same size will have a high frequency probe, the wave discontinuity of the wider will be returned. The effect of fault diagnosis with unfavorable orientation, especially if a large, flat plate are ( not like melted roots ) the double-sided welds, helps.

**3- Transducer size:** Small transducer, is less than the length and width of the wave propagation in the near field and far greater divergence, leads to a specific frequency.
The small probe with a diameter of 5 to 10 mm transducer (or transducers quadrilateral with the same area) when the near field test range (short wavelength direction) is performed are very useful. For larger areas (greater than 100 for normal probe and greater than 200 mm for angular probe) transducer diameter of about 15 to 25 mm is ideal.

**4- Pulse duration:** In signal processing, pulse duration is the interval between the time, during the first transition, that the amplitude of the pulse reaches a specified fraction (level) of its final amplitude, and the time the pulse amplitude drops, on the last transition, to the same level. The interval between the 50% points of the final amplitude is usually used to determine or define pulse duration, and this is understood to be the case unless otherwise specified(Figure1). Other fractions of the final amplitude, e.g., 90% may also be used, as may the root mean square ($rms$) value of the pulse amplitude. In radar, the pulse duration is the time the radar's transmitter is energized during each cycle[7].

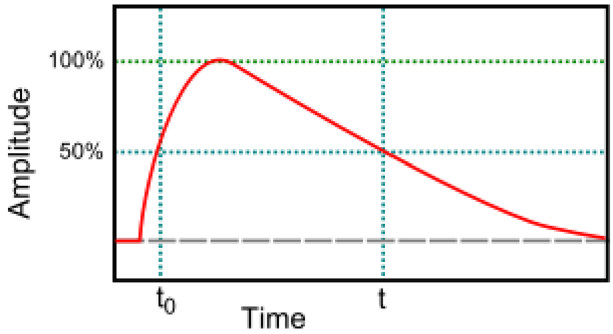



**Figure1.** Pulse duration using 50% peak amplitude

**5- Probe stand shape:** When parts are tested less than 150 mm in diameter, which is much better as the basic guide for the scanning probe is self-made.However, if it is allowed to probe design, the deformation permitted. This prevents the probe oscillation and coupling conditions improve, and work on the curved surface wave transmission decreases. Probe basic shape of the curve, it is necessary to determine the parameters of the test block probe, calibration and sensitivity settings are applied to the base of the curve to be constructed. Figure2 shows an example of a probe stand.

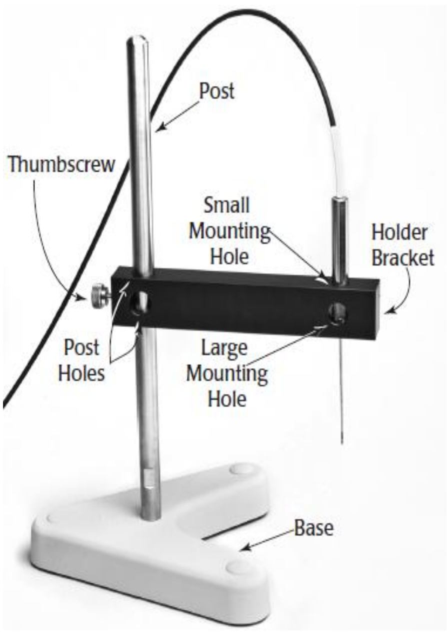



**Figure2.** The Universal Dipping Probe Holder. Rotate the Holder Bracket 90º to hold a standard a SpectroPipetter.

**6- Probe angle:**

While straight beam techniques can be highly effective at finding laminar flaws, they are not effective when testing many common welds, where discontinuities are typically not oriented parallel to the surface of the part. The combination of weld geometry, the orientation of flaws, and the presence of the weld crown or bead require inspection from the side of the weld using a beam generated at an angle. Angle beam testing is by far the most commonly used technique in ultrasonic flaw detection.
Angle beam probes consist of a transducer and a wedge, which may be separate parts or built into a single housing. They use the principle of refraction and mode conversion at a boundary to produce refracted shear or longitudinal waves in a test piece as shown below (Figur3).

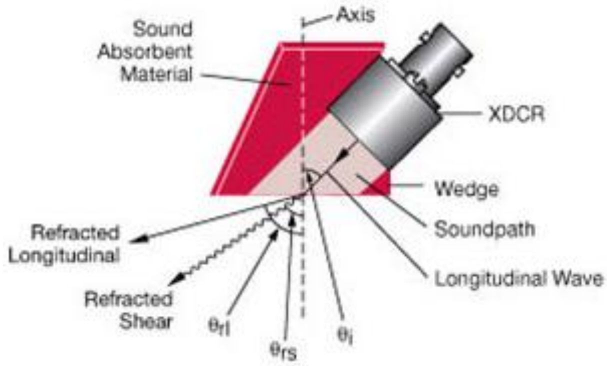



**Figure3.** Schematic diagram of a probe angular components

Most commonly used angle beam probes generate a refracted shear wave at standardized angles of $45^o$, $60^o$, or $70^o$ in the test material. The incident angle necessary to produce a desired refracted angle is based on material sound velocities and is calculated from Snell's Law through the equation below[8].

$$\sin\theta_i / c_i = \sin\theta_{rl} / c_{rl} = \sin\theta_{rs} / c_{rs}$$

$\theta_i$ = Incident Angle of the Wedge, $\theta_{rl}$ = Angle of the refractad Longitudinal Wave
$\theta_{rs}$ = Angle of the refractad Shear Wave, $c_i$ = Velocity of the Incident Material (Longitudinal)
$c_{rl}$ = Material Sound Velocity(Longitudinal), $c_{rs}$ = Velocity of the Test Material (Shear)

In the typical case of a plastic or epoxy wedge coupled to steel, low incident angles will generate both longitudinal and shear wave beam components, and specialized longitudinal wave angle beam wedges do exist(Figure4). However at commonly used inspection angles only a primary shear wave will be generated, since the L-wave solution to the equation would exceed 90 degrees, which is not possible.

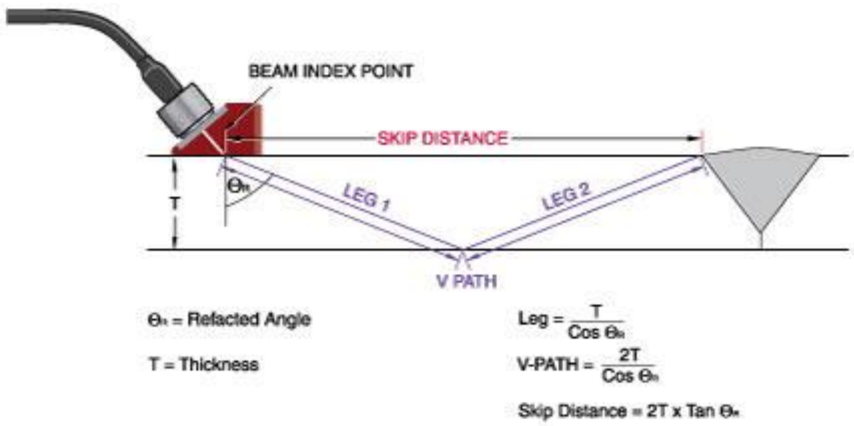



**Figure4.** Low incident angles generate both longitudinal and shear wave beam components

In typical inspections the sound beam will travel at the generated angle down to the bottom of the test piece and then reflect upward at the same angle. As seen in Figure5, moving the probe back and forth causes the sound beam to sweep across the full height of a weld. This scanning motion enables inspection of the entire weld volume and detection of discontinuities both at the fusion lines and within the weld body.


**Figure5.** Sweep across the full height of a weld

As in the case of straight beam testing, in angle beam testing the operator looks for reflections corresponding to discontinuities. During initial setup the operator must note any echoes that originate from weld bead or other geometric structures. Additional echoes appearing within the zone representing the weld would correspond to a lack of fusion, cracking, porosity, or other discontinuities whose type, depth, and size can be determined through further analysis.
In the example below (Figure6), the sound beam passes through a good weld without reflecting back, and no significant indications are seen on the screen. A discontinuity within the weld zone, however, causes a strong reflection with the zone of interest marked by the red gate[8,9].

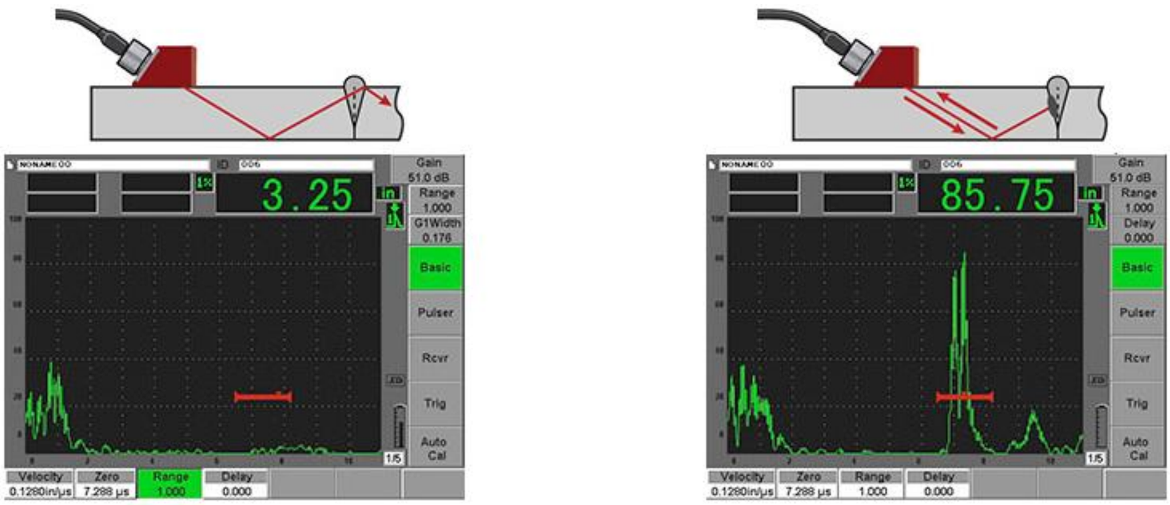



**Figure6.** Good weld without reflecting back and a discontinuity within the weld zone causes a strong reflection

**7- Single/dual crystals probe:**

The single-crystalline probes, ultrasonic waves are sent and received by a crystal. In other words, the waves echo back the device to send and receive the back wall or a disadvantage. The crystals began to shake, the mechanical energy into electrical interface device is transmitted by wire.
Because we use the probe single-crystalline vibrations transmitted by the crystal by crystal immediately after hitting the Perspex probe is received, we will always return the first CRT Initial Pulse is called an echo. This causes the defects in the test piece is not obvious.
Due to imperfections in CRT to an area that may not be diagnosed Initial Pulse called Dead Zone. Two crystal probes are designed to minimize this problem because two such crystals have been probe with specific angle into the waves by a crystal into pieces after it is received by the second crystal. Also, to prevent interference probe inside a sound-resistant layer is placed across the two crystals. These types of probes are available in both

normal and wide angle market. These probes are calibrated by two different thicknesses of. Acoustic walls between transmitter and receiver crystals of finite thickness will cause a dead zone. This type of probe for calibration requires the use of two different thicknesses. Usually less than 20mm thickness can be tested with this type of probe. Overall, this probe has the following advantages and disadvantages.

**advantages:**

- Suitable for measuring thin piece
- Defects close to the surface can be detected.
- Near-surface defects are at high resolution.

**disadvantages:**

- They cannot easily be used on uneven surfaces.
- Correct diagnosis of small defects due to further probe the width of two crystalline than the conventional probe. So the two crystal probe is used mainly as a complementary probe.

Done to increase the speed of the test cases that we tested a wide range of other probes, called a probe is used to mosaic. This limits the sensitivity of the probe is relatively small and is only approximate location of the fault can be identified. So after using these probes, we proceeded to test the desired level, using a single probe crystalline attempt to determine the exact location and size of a fault the charges.

**8- Special Probes for special inspection tasks**

As manifold as the inspection tasks are also the used special probes and thus the special properties of such probes. Some examples for the verification within this broad spectrum of probes for the manual and automated inspection are presented in this article[10-11].

**8-1- The automated inspection of new rails**

A testing machine for new rails has to detect in homogeneities within the complete intersection of the rail. It is decisive that only small region may be uninspected. The ultrasonic coupling is done by water jetting, see figure7 for the vertical inspection of a rail. Because of the necessary covering of the volume several probes of the same type are applied and this requires the measurement and verification of the sound beam properties. Figure8 represents an according probe certification for the probe type IAP6.12,7.130. In this case it is required to determine the sound pressure curve versus the distance, the sound distribution in the vertical plane, as well as the sound distribution in the focal plane and the according pressure profiles perpendicular to the acoustical axis. All these sound pressure distributions are presented in the probe inspection report.

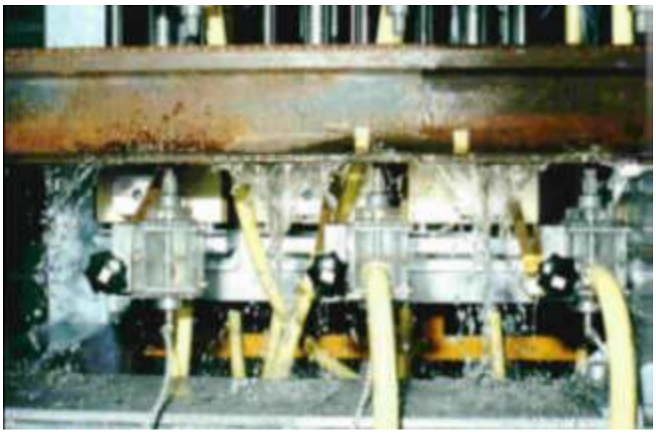


**Figure7.** vertical inspection of a rail

### 8-2- The automated inspection of steel plates with Dual Probes (T / R)

T/R-probes contain separated oscillators for the transmission and reception. For the steel plate inspection probes with a large transmitter and 3 small receiver oscillators are applied, e.g. the type SEZ5R10RS. The sound beam properties are determined at a defined distance of the reference reflector. The figures9 and 10 present some examples for the measured sound beam of the large transmitter and the form and position of the sound beams of the 3 small receivers. The selected color coding covers a range of 18 dB. For this case it is important that the geometry of the sound beams are similar and that they cover the volume completely.

### 8-3- The automated inspection of tubes

The detection of longitudinal defects in tubes means of "Rotation Inspection Systems" requires probes with a line focused sound beam. In order to achieve very high inspection speeds, several probes of the same type are used in parallel. Also here it is important to verify that the sound beams overlap in order to cover the volume without any gaps. To ensure this it is has to be certified that the sound pressure distance curves and the sound distributions parallel and perpendicular to the focus line are constant. An example for the probe H5KTL30 given in figure11.

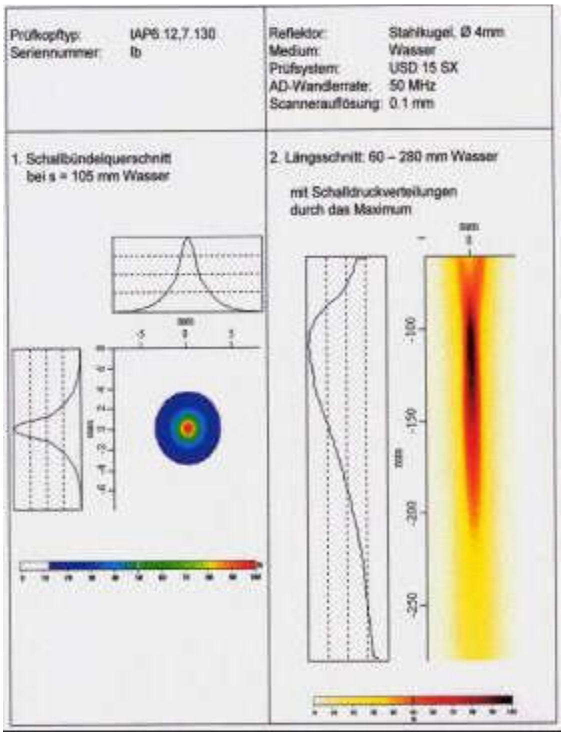
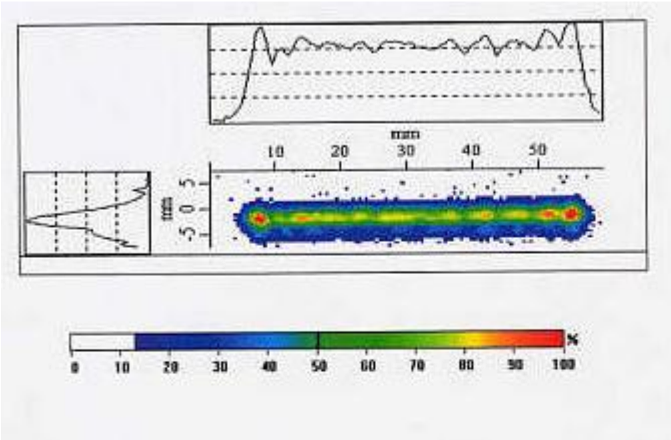



**Figure8.** represents an according probe certification




**Figur9.** measured sound beam of the large transmitter

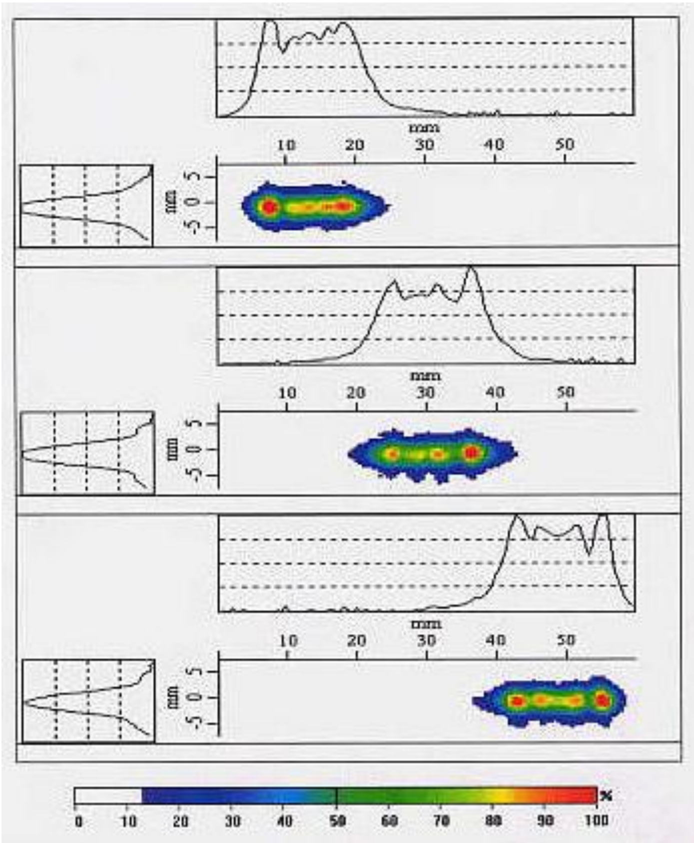



**Figure10.** measured sound beams of the 3 small receivers

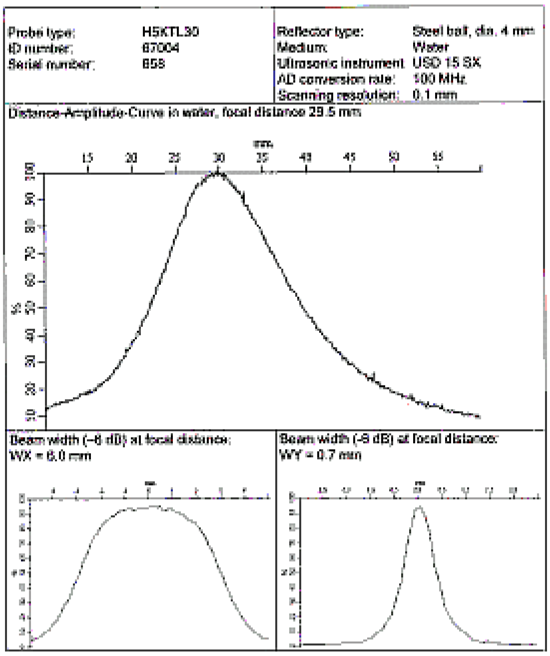



**Figure11.** Automated inspection of tubes by probe H5KTL30

### 8-4- The automated inspection of laminated products by means of wide sound beams

Wide inspection zones are generally realized using long rectangular oscillators. The size of the oscillator and the acoustical wavelength define the diffracted sound beam of the plane oscillator. If convex sound lenses are used or if the oscillator itself is bended, it is possible to widen up the sound beam divergence without any affect on the focusing effect in the other axis. (Of course this reduces the sensitivity.)
Figure12 presents the grey value coded sound distribution in the longitudinal plane for such a defocusing transducer with a width of 12 mm · 12 mm with a bending radius of 50 mm. It also shows the according sound beam intersections in three different distances: Before the line focus, in the focus and behind it.
The verification of the sound beam widening, which depends on the oscillator's bending radius, had to be done by using a side drilled hole with the diameter 1.6 mm in a tube wall with a thickness of 3.5 mm. The measured results are presented in figure13 for four cases: for a plane line focused oscillator and the defocused oscillators with bending radii of 100 mm, 75 mm and 50 mm. It can be read out that the inspection zone concerning the side drilled hole reflection increases from 9,0 mm to 14,6 mm.

### 8-5- The manual inspection of resistance spot welds

Resistance welded spots are inspected by means of vertical probes with a special design for this inspection task, see figure14. In order to detect too small spot weld nuggets it requires that the sound beam diameter is equal to the nominal nugget diameter in the region of interest. Therefore only those probes which are certified accordingly shall be used for the inspection of the spot welds e.g. in the automobile industry. The figures15 and 16 represent two certificates, one for the probe G20MN4,0 for a nominal nugget diameter of 4 mm and the other for the probe G20MN5,6 for a nugget of 5,6 mm. Additionally it also shows the axial sound pressure distribution.

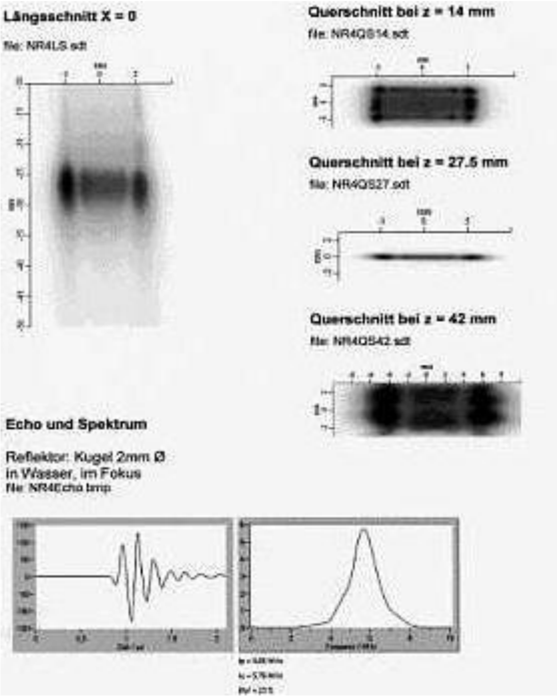



**Figure12.** Grey value coded sound distribution in the longitudinal

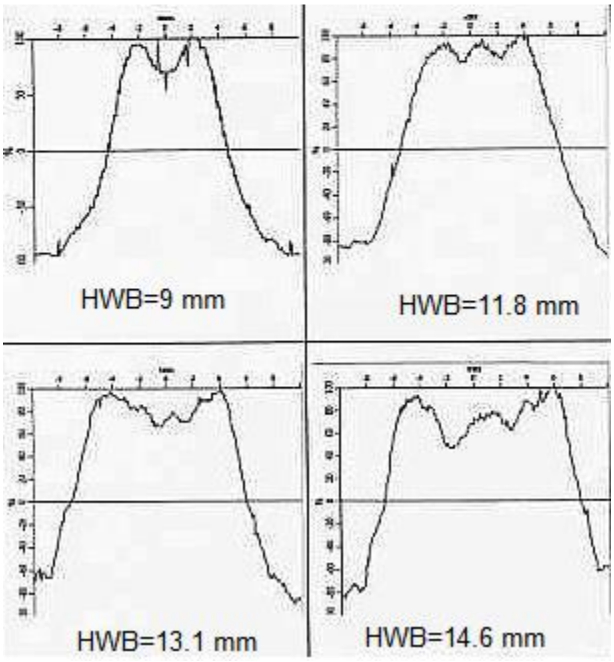



**Figure13.** The measured results from verification of the sound beam widening, which depends on the oscillator's bending radius

**Figure14.** vertical probe for inspection of spot weld

## 9- Conclusion

In case of standard probes a general technical probe data sheet and a conformity declaration of the manufacturer according to the standard EN 12668-2 is enough. But special probe designs require individual verifications of the probe properties, which refer exactly to the special inspection task.
These can be defined sound pressure distributions or defined sound beam diameters. Sometimes also the interaction of the sound beam with predetermined reference reflectors must be verified. This requires scanning devices which exceed the measurement devices described in EN12668-2.

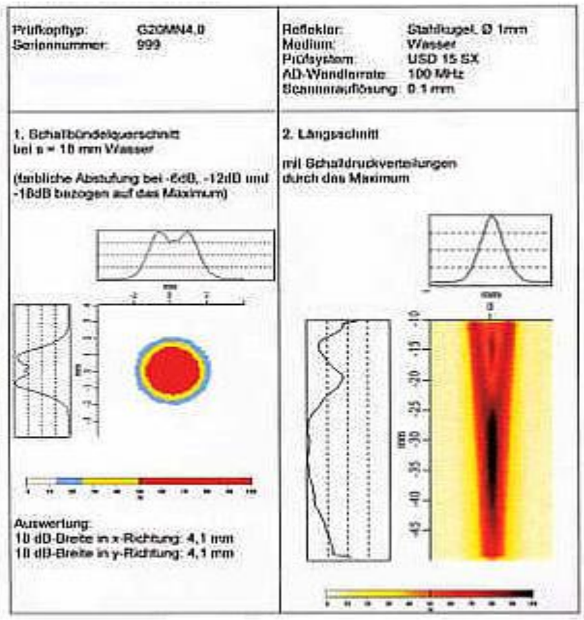



**Figure15.** The probe G20MN4.0 for a nominal nugget diameter of 4 mm

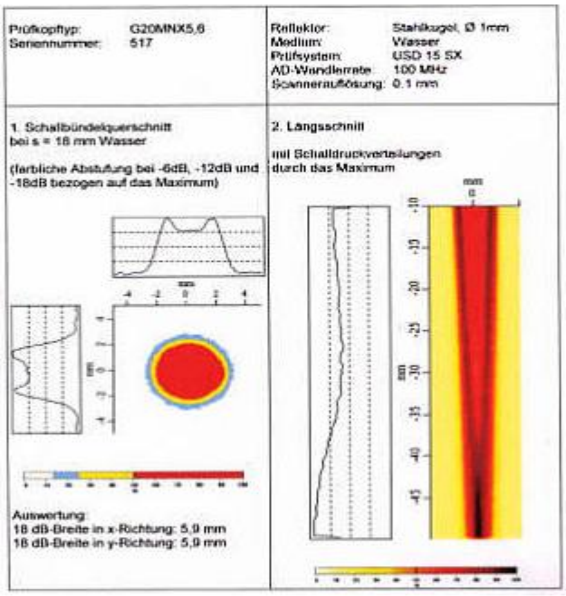



**Figure16.** The probe G20MN5.6 for a nominal nugget diameter of 5,6 mm.

**References:**


[1]. Leung, M.L.H.; Lai-Wah, H.C.; Chou-Kee, P.L. "Comparison of bonding defects for longitudinal and transverse thermosonic flip-chip." In 2003 Electronics Packaging Technology Conference,10-12 December 2003; pp. 350-355.

[2]. Mayer, M. "Microelectronic bonding process monitoring by integrated sensors." Hartung-Gorre: Konstanz, Germany, 2000; pp. 28-34.

[3]. Chiu, S.S.; Chan, H.L.W.; Or, S.W.; Cheung, Y.M.; Liu, P.C.K. "Effect of electrode pattern on the outputs of piezosensors for wire bonding process control." Mater. Sci. Eng. 2003, B99, 121-126.

[4]. Han, L.; Zhong, J.; Gao, G.Z. "Effect of tightening torque on transducer dynamics and bond strength in wire bonding." Sens. Actuat. A 2008, 141, 695-702.

[5]. Chua, P.W.P.; Li, H.L.; Chan, H.L.W.; Ng, K.M.W.; Liu, P.C.K. "Smart ultrasonic transducer for wire-bonding applications." Mat. Chem. Phys. 2002, 75, 95-100.

[6]. Chua, P.W.P.; Chong, C.P.; Chan H.L.W.; Ng, K.M.W.; Liu, P.C.K. "Placement of piezoelectric ceramic sensors in ultrasonic wire-bonding transducers." Microelectron. Eng. 2003, 66, 750-759.

[7]. Parrini, L. "New technology for the design of advanced ultrasonic transducers for high-power applications." Ultrasonics 2003, 41, 261-269.

[8]. Tsujino, J.; Yoshihara, H.; Sano, T.; Ihara, S. "High-frequency ultrasonic wire bonding systems." Ultrasonics 2000, 38, 77-80.

[9]. Or, S.W.; Chan, H.L.W.; Liu, P.C.K. "Piezocomposite ultrasonic transducer for high-frequency wire-bonding of microelectronics devices." Sens. Actuat. A 2007, 133, 195-199.

[10]. Parrini, L. "Advances process characterization for 125 kHz wire bonder ultrasonic transducer." IEEE Trans. Compon. Packag. Technol. 2002, 25, 486-494.

[11]. Chylak, B.; Qin, I.W.; Eder, J. "Achieve Optimal Wire Bonding Performance through Ultrasonic System Improvement." Kulicke and Soffa Industries, Inc, SEMICON® Singapore 2004.