Practical challenges during high temperature ultrasonic scanning

Mr. P. Sukumaran
Reliability & Maintenance Department, Equate Petrochemical Company
Ahmadi, Kuwait
Email: sukimap@equate.com

Background: Although most ultrasonic flaw detection and thickness gauging is performed at normal environmental temperatures, there are many situations where it is necessary to test a material that is hot. This is most commonly happens in process industries, where hot metal pipes, pressure vessels or tanks must be tested without shutting them down for cooling.

Challenges during High Temperature scanning:

The Ultrasonic operator will face lot of difficulties to achieve reliable inspection and to capture the most possible and probable dis-continuities present in the target locations.
Though the challenges are many and some of them will be discussed in brief and probe angle deviation due to elevated temperature will be discussed in detail.

1. **Hot environment:** First the operator feels discomfort while doing scanning due to hot environment, where the probability of detection goes down. This is human psychological factor where the reliability of detection is also goes down. So, we can try to eliminate this by providing localized air condition system as much as we can.

2. **Velocity Variation:** Sound velocity in all materials changes with temperature, slowing down as the material heats up. Accurate ultrasonic gauging or Flaw detection of hot materials always requires velocity recalibration. In steel, this velocity change is approximately 1% per 55° C or 100° F change in temperature. (The exact value varies depending on the alloy.) In plastics and other polymers, this change is much greater, and can approach 50% per 55° C or 100° F change in temperature up to the melting point. If a temperature/velocity plot for the material is not available, then a velocity calibration should be performed on a sample of the test material at the actual test temperature. For flaw detection, sensitivity setting to be done on the heated calibration block of similar material or as allowed by code within the allowable temperature variation as per code.

3. **Increased Attenuation:** Sound attenuation in all the materials increases with increasing temperature, and the effect is much more pronounced in plastics than in metals or ceramics. In typical fine grain carbon steel alloys, attenuation at 5 MHz at room temperature is approximately 2 dB per 100 mm one-way sound path (equivalent to a round trip path of 50 mm each way). At 500° C or 930° C, attenuation increases to approximately 15 dB per 100 mm of sound path. This effect can require use of significantly increased instrument gain when testing over long sound paths at high temperature, and can also require adjustment to distance/amplitude correction (DAC) curves or TVG (Time Varied Gain) programs that were established at room temperature. Temperature/attenuation effects in polymers are highly material dependent, but will be typically be several times greater than the above numbers for steel. In particular, long high temperature delay lines that have heated up may represent a significant source of total attenuation in a test.

4. **Gain Boost:** Because of the higher attenuation levels associated with high temperature measurements, it is often necessary to increase the gain in order to get proper sensitivity as needed. If we increase the gain, back ground spurious indications will disturb the inspection.
5. **Coupling Technique**: The couplant dries out quickly on the hot surface which affects the sensitivity and require periodic cleaning of the dried couplant and re-apply new couplant. The combination of transducer duty cycle requirements and the tendency of couplants to solidify or boil off at the upper end of their usable thickness range require quick work on the part of the operator. Many users have found the best technique to be, to apply a drop of couplant to the face of the transducer and then press the transducer firmly to the test surface, without twisting or grinding it (which can cause transducer wear). Any dried couplant residue should be removed from the transducer tip between measurements. It is important to be aware of the specified temperature range for their use, and use them only within that range. Poor acoustic performance and/or safety hazards may result from using high temperature couplants beyond their intended range.

6. **Probe Duty Cycle**: All standard high temperature transducers are designed with a duty cycle in mind. Although the delay line insulates the interior of the transducer, lengthy contact with very hot surfaces will cause significant heat buildup, and eventually permanent damage to the transducer if the interior temperature becomes hot enough. For most dual element and delay line transducers, the recommended duty cycle for surface temperatures between approximately 90° C and 425° C (200° F to 800° F) is no more than ten seconds of contact with the hot surface (five seconds is recommended), followed by a minimum of one minute of air cooling. Note that this is guideline only; the ratio of contact time to cooling time becomes more critical at the upper end of a given transducer's specified temperature range. As a general rule, if the outer case of the transducer becomes too hot to comfortably hold with bare fingers, then the interior temperature of the transducer is reaching a potentially damaging temperature and the transducer must be allowed to cool down before testing continues.

7. **Angular Variation in Wedges**: With any high temperature wedge, sound velocity in the wedge material will decrease as it heats up, and thus the refracted angle in metals will increase as the wedge heats up. If this is of concern in a given test, refracted angle should be verified at actual operating temperature. As a practical matter, thermal variations during testing will often make precise determination of the actual refracted angle difficult.
Case study on probe angle variation with respect to temperature rise.

Probe characteristics may vary substantially as a function of temperature. This fact is well known and it is caused by the fact that damping and ultrasound velocity change as temperature is increased. Although this effect occurs in both steel as well as wedge material of the probe it is most pronounced in the probe wedge. The damping increase and the ultrasonic velocity drops.

During inspection, it was observed that Panametrics probes (marking on the wedge 45 degree steel 480 degree C Max, wedge type ABWHT-3. Probe type A409 S 5.0/1.0 316579) joint together with sufficient and suitable HT couplant displayed an effective insertion angle of 48 degrees at ambient temperature and 51 degree when put it on the block heated above 200 degrees Celsius.

First of all it is noteworthy that the insertion angle at ambient temperature appears to deviate from specified angle (45 degree). The probe index was determined on the 100 mm radius of a certified V1 block, by optimizing the echo amplitude on the radius. The index point is about 4.5 mm (+/-1 mm accuracy) behind the centre line of the probe indicated on the wedge. This is caused by the damping of the ultrasound in the wedge. Damping increase quadratically as a function of frequency, so the effect will be more pronounced with 5 MHz probes than with 3 MHz probes. At elevated temperatures the damping increases so the index point shifts back even further to about 6 mm behind the centre line of the probe.

The insertion angle of the probe was further determined on the V1 block, using the actual index point at a reference. The position of optimum reflection is shown in photo 1. The insertion angle at ambient temperature is 48 degrees when the actual index point is taken as a reference. When the probe centre is taken as a reference the angle is 46 degrees, but clearly there is no physical ground for taking this centre point as a reference as explained above.
To further corroborate the observation that the probe angle shifts as a function of temperature, the ultrasonic velocity as a function of temperature was measured. For this purpose the HT wedge was heated and temperature was measured using an infrared temperature measurement. (Raytek-mini temp). Ultrasonic velocity was measured from the first back wall echo when the probe was placed on the side of the wedge (Photo 2). Echo amplitude was brought to 80% FSH reference for each measurement. To avoid damage to the probe, no measurements were taken beyond 160°C.
photo 2: Set-up for wedge ultrasound velocity measurements. For actual measurement the echo amplitude was brought down to 80 % FSH reference.

During the measurements it was observed that the wedge heats up slowly and non uniform due to the low heat conduction coefficient of the wedge material.

The result of the temperature measurement is shown in fig. 1.
The result clearly shows that UT velocity in the wedge decreases substantially as temperature increases. The UT velocity in steel also decreases as a function of temperature, however, this decrease is much less pronounced than in the wedge material. The longitudinal UT velocity in a HY-80 calibration block was shown to decrease by about 4% when the block was heated to 200 degrees Celsius. Assuming that the shear velocity shows the same behavior, the UT velocity at 240 C will drop to 3050 m/s from an initial 3250 m/s at room temperature. Simply applying Snell’s law on those results it becomes quite clear that the effect of temperature increase is that the insertion angle will increase too.

In fig. 2 the angle as a function of temperature is shown as a function of wedge temperature and calculated angle from the measured velocities. The angles above 160 C are extrapolated from the results in Fig. 1.
Fig.2: Probe angle as a function of wedge temperature.

Comparison of the calculated results with the angle observed in the field, suggests that the intermittent use of the wedge (the wedge is never used continuously to avoid damage to the probe) results in an effective wedge temperature of about 120 - 140 degrees Celsius.

It may also be concluded that the angle indicated on the wedge is valid only at ambient temperature using the centre line of the probe as a reference.

So, suggested to check the correct shear wave angle of that particular probe/wedge while scanning on high temperature surface. There is a drastic change in angle which will mislead to wrong interpretation of dis-continuities, if we adopt the standard probe angle or simply calculating the probe angle by substituting the sound velocity change in the material by using Snell’s law formula, we will end up the wrong angle.
Hence, we need to consider the velocity changes in the wedge material which plays a major role in the shear wave angle changes than the velocity changes in the material.

References:

3. ASNT Hand book on Ultrasonic testing.
4. Experiment and lab test reports.

Author of this article, P. Sukumaran, ASNT NDT Level-III RT, UT, MT, PT & VT. #99552.