Corrosion Gauging with Dual Element Transducers

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Application:
Use of dual element transducers ("duals") for measurement of remaining metal thickness in corrosion applications.

Problem:
Just about anything that is made of common structural metals can be subject to corrosion. A particularly important problem that faces many industries is measurement of remaining wall thickness in pipes, tubes, or tanks that may be corroded on the inside surface. Such corrosion is often not detectable by visual inspection without cutting or disassembling the pipe or tank. Structural steel beams, particularly bridge supports and steel pilings, are also subject to corrosion that reduces the original thickness of the metal. If undetected over a period of time, corrosion will weaken walls and possibly lead to dangerous structural failures. Both safety and economic considerations require that metal pipes, tanks, or structures that are subject to corrosion be inspected on a regular basis. Ultrasonic testing is a widely accepted nondestructive method for performing this inspection, and ultrasonic testing of corroded metal is usually done with dual element transducers.

Theory Of Operation:
It is the irregular surfaces that are frequently encountered in corrosion situations that give duals an advantage over single element transducers. All ultrasonic gauging involves timing the round trip of a sound pulse in a test material. Because solid metal has an acoustic impedance that differs from that of gasses, liquids, or corrosion products such as scale or rust, the sound pulse will reflect from the far surface of the remaining metal. The test instrument is programmed with the velocity of sound in the test material, and computes the wall thickness from the simple formula Distance = (Velocity) X (Time). Most gauges designed for corrosion applications measure the roundtrip transit time interval to the first backwall echo. A few instruments measure the interval between successive multiple echoes. While this technique is effective for precision gauging of smooth materials, it is usually ineffective at detecting pitting and measuring true minimum thickness of corroded pipe or tank walls. It is not recommended for corrosion gauging.
Dual element transducers incorporate separate transmitting and receiving elements, mounted on delay lines that are usually cut at an angle to the horizontal plane (the roof angle), so that the transmitting and receiving beam paths cross beneath the surface of the test piece. This crossed-beam design of duals provides a pseudo - focussing effect that optimizes measurement of minimum wall thickness in corrosion applications. Duals will be more sensitive than single element transducers to echoes from the base of pits that represent minimum remaining wall thickness. Also, duals may often be used more effectively on rough outside surfaces. Couplant trapped in pockets on rough sound entry surfaces can produce long, ringing interface echoes that interfere with the near surface resolution of single element transducers. With a dual, the receiver element is unlikely to pick up this false echo. Finally, duals may be designed for high temperature measurements that would damage single element contact transducers.

Equipment:
A number of small, hand-held microprocessor-based ultrasonic thickness gauges have been specifically designed for corrosion survey applications. Typically these gauges will be used with a dedicated group of dual element transducers, covering various thickness ranges and temperature conditions.
In some critical applications, especially at elevated temperatures, a user may require an ultrasonic waveform display to help verify that valid echoes are being detected. The Panametrics Model 36DL PLUS is a hand-held corrosion gauges with waveform display that is designed for such cases. For full details, see the Model 36DL PLUS datasheet. If a waveform display is not required, other instruments designed for this type of testing include the compact and simple Model 26MG and 26MG-XT gauges.
In corrosion applications, duals can be used effectively with flaw detectors as well. Digital flaw detectors such as the Panametrics EPOCH series (EPOCH III, EPOCH IIIB, EPOCH II, and EPOCH IIB) provide a thickness measurement as well as a waveform display.

Procedure:
The following general principles apply to all corrosion measurements with dual element transducers, whether used with a portable gauge such as the 36DL PLUS or a flaw detector. Keep in mind that in

all cases the instrument must be properly calibrated for sound velocity and zero offset in accordance with the procedure found in the instrument's operating manual.

1. Transducer Selection:
For any ultrasonic measurement system (transducer plus thickness gauge or flaw detector) there will be a minimum material thickness below which valid measurements will not be possible.
Normally this minimum range will be specified in the manufacturer's literature. As transducer frequency increases, the minimum measurable thickness decreases. In corrosion applications, where minimum remaining wall thickness is normally the parameter to the measured, it is particularly important to be aware of the specified range of the transducer being used. If a dual is used to measure a test piece that is below its designed minimum range, the gauge may detect invalid echoes and display an incorrectly high thickness reading.
The table below list approximate minimum measurable thickness in steel for the standard transducers used with the Panametrics Model 26DL, 26MG, 26MG-XT, and 36DL PLUS gauges. Note that these numbers are approximate. The exact measurable minimum in a given application depends on material velocity, surface condition, and geometry, and it should be determined experimentally by the use.

Transducer	Dia./Freq.	Connector	Minimum Thickness	Temp. Limit**
D790-SM	.434"/5MHz	Straight Replaceable Cable LCMD-316-5B**	0.040"/1mm	A
D790	.434"/5MHz	Straight	0.040"/1mm	A
D791-RM	.434"/5MHz	Right Angle Replaceable Cable LCMD-316-5C	0.040"/1mm	C
D791	.434"/5MHz	Right Angle	0.040"/1mm	A
D792	.283"/10MHz	Straight	0.020"/0.5mm	B
D793	.283"/10MHz	Right Angle	0.020"/0.5mm	B
D794	.283"/5MHz	Straight	0.030"/0.75mm	B
D795	.283"/5MHz	Right Angle	0.030"/0.75mm	B
D797-SM	.900"/2MHz	Straight Replaceable Cable LCMD-316-5D	0.100"/2.5mm	C
D797	.900"/2MHz	Right Angle	0.100"/2.5mm	C
D798	.290"/7.5MHz	Right Angle	0.028"/0.7mm	B
D799	.434"/5MHz	Right Angle	0.040"/1mm	D
D7226	.350"/8.9mm	Right Angle	0.028"/0.7mm	D
MTD705*	.310"/5MHz	Right Angle Replaceable Cable LCLPD-78-5	0.030"/0.75mm	B

* The MTD705 transducer is compatible with Models 26MG, 26MG-XT, 26DL PLUS, and 36DL PLUS only.

** Key To Temperature Limits

A	-20 deg TO +500 deg C	OR	-5 deg TO +932 deg F
B	0 deg TO +50 deg C	OR	+32 deg TO +122 deg F
C	-20 deg TO +400 deg C	OR	-5 deg TO +752 deg F
D	-20 deg TO +150 deg C	OR	-5 deg TO +300 deg F

In selecting a transducer for a corrosion application it is also necessary to consider the temperature of the material to be measured. Not all duals are designed for high temperature measurements. The chart above lists recommended temperature ranges for the Panametrics duals used with the 36DL PLUS or 26 Series gauges. For other transducers, consult the manufacturer's catalogue or data sheets. Using a transducer on materials whose temperature is beyond the specified range can damage or destroy the transducer.

2. Surface Condition:
Loose or flaking scale, rust, corrosion or dirt on the outside surface of a test piece will interfere with the coupling of sound energy from the transducer into the test material. Thus, any loose debris of this sort should be cleaned from the specimen with a wire brush or file before measurements are attempted. Generally it is possible to make corrosion measurements through thin layers of rust, as

long as the rust is smooth and well bonded to the metal below. Some very rough cast or corroded surfaces may have to be filed or sanded smooth in order to insure proper sound coupling. It may also be necessary to remove paint if it has been applied in thick coats, or if it is flaking off the metal. While it is often possible to make corrosion measurements through thin coats of paint (on the order of a few thousandths of an inch or 0.1 - 0.2mm), thick paint will attenuate signals or possibly create false echoes. Instruments that claim the ability to measure through thick paint layers are usually unable to detect pitting, and thus fail to measure true minimum thickness of remaining metal.
Severe pitting on the outside surface of a pipe or tank can be a problem. On some rough surfaces, the use of a gel or grease rather than a liquid couplant will help transmit sound energy into the test piece. In extreme cases it will be necessary to file or grind the surface sufficiently flat to permit contact with the face of the transducer. In applications where deep pitting occurs on the outside of a pipe or tank it is usually necessary to measure remaining metal thickness from the base of the pits to the inside wall. There are sophisticated ultrasonic techniques utilizing focussed immersion transducers that can measure directly form the base of the pit to the inside wall, but this is generally not practical for field work. The conventional technique is to measure unpitted metal thickness ultrasonically, measure pit depth mechanically, and subtract the pit depth from the measured wall thickness. Alternately, one can file or grind the surface down to the base of the pits and measure normally.
As with any difficult application, experimentation with actual product samples is the best way to determine the limits of a particular gage/transducer combination on a given surface.

3. Transducer Positioning/Alignment:
For proper sound coupling the transducer must be pressed firmly against the test surface. On small diameter cylindrical surfaces such as pipes, hold the transducer so that the sound barrier material visible on the probe face is aligned perpendicular to the center axis of the pipe. See the illustration below.
While firm hand pressure on the transducer is necessary for good readings, the probe should never be scraped along or twisted against a rough metal surface. This will scratch the face of the transducer and eventually degrade performance. The safest technique for moving a transducer along a rough surface is to pick it up and reposition it for each measurement, not to slide it along.
Remember that an ultrasonic test measures thickness at only one point within the beam of the transducer, and that in corrosion situations wall thicknesses often vary considerably. Test procedures usually call for making a number of measurements within a defined area and establishing a minimum and/or average thickness. Ideally, data should be taken at increments no greater than half the diameter of the transducer, to insure that no pits or other local variations in wall thickness are missed. It is up to the user to define a pattern of data collection appropriate to the needs of a given application.
It is possible that on some severely corroded or pitted materials there will be spots where readings cannot be obtained. This can happen when the inside surface of the material is so irregular that the sound energy is scattered rather than being reflected back to the transducer. Lack of a reading may also indicate a thickness outside the range of the transducer and instrument being used. Generally, an inability to obtain a valid thickness reading at a particular point on a test specimen could be a sign of a seriously degraded wall which may warrant investigation by other means.

4. High temperature Measurements:
Corrosion measurements at elevated temperatures require special consideration. Keep in mind the following points:

- Be sure that the surface temperature of the test piece does not exceed the maximum specified temperature for the transducer and couplant that you are using. Some duals are designed for room temperature measurements only.
- Use a couplant rated for the temperature where you will be working. All high temperature couplants will boil off at some temperature, leaving a hard residue that is not able to transmit sound energy. Panametrics Couplant E-2A (Thermotemp) can be used at temperatures up to 900 deg F/470 deg C, although it will harden as the upper limit is reached. Maximum recommended temperatures for Panametrics couplants are as follows:

COUPLANT TYPE	MAXIMUM RECOMMENDED	TEMPERATURE
A	Propylene Glycol	300 deg F/150 deg C
B	Glycerine	200 deg F/90 deg C
D	Gel	200 deg F/90 deg C
E	High Temperature	900 deg F/470 deg C
F	Medium Temperature	540 deg F/260 deg C

- Make measurements quickly and allow the transducer body to cool between reading. High temperature duals have delay lines made of thermally tolerant material, but with continuous exposure to very high temperatures the inside of the probe will heat to a point where bonds will fail, destroying the transducer.
- Remember that both material sound velocity and transducer zero offset will change with temperature. For maximum accuracy at high temperatures, velocity calibration should be performed using a section of the test bar of known thickness heated to the temperature where measurements are to be performed. The Panametrics Model 26 Series gauges and the 36DL PLUS have a semi-automatic zero function that can be employed to adjust zero setting at high temperatures. See the instrument operating manual for details. For other gauges and flaw detectors, see their operating manual for information on how to compensate for zero drift at elevated temperatures.

5. Gauges and Flaw Detectors:
An ultrasonic corrosion gauge is designed to detect and measure echoes reflected from the inside wall of a test piece. It is possible that material discontinuities such as flaws, cracks, voids, or laminations may produce echoes of sufficient amplitude to trigger the gauge, showing up as unusually thin measurements at particular spots on a test piece. However, a corrosion gauge is not designed for flaw or crack detection, and cannot be relied upon to detect material discontinuities. A proper evaluation of material discontinuities requires an ultrasonic flaw detector such as the Panametrics Epoch III used by a properly trained operator. In general, any unexplained readings by a corrosion gauge merit further testing with a flaw detector.

Dual Element Transducers

Application:
This application note contains general background information on the use of dual element delay line contact transducers, generally known as "duals", "pitch and catch", or "SE probes", in flaw detection and thickness gauging applications. It also discusses Panametrics Extended Range duals.
Dual element transducers incorporate separate transmitting and receiving elements, mounted on delay-lines that are usually cut at an angle to the horizontal plane (the "roof angle"), so that the transmitting and receiving beam paths cross beneath the surface of the test piece.

Advantages of Duals:
Dual element transducers have the following advantages over single element contact and delay line transducers:

- The crossed-beam design of duals provides a pseudo-focussing effect that optimizes measurement of minimum wall thickness on corroded materials. Duals will be more sensitive than single element transducers to echoes from the base of pits that represent minimum remaining wall thickness in corrosion applications.
- Duals may often be used effectively on rough surfaces. Rough sound entry surfaces produce long, ringing interface echoes that interfere with the near surface resolution of single element transducers. With a dual, the receiving element is in principle not exposed to the interface echo.
- A single element probe cannot detect returning echoes until it has ceased transmitting. Additionally, thin material resolution may be limited by saturation of the receiver amplifier by the excitation pulse. These two factors create a dead zone at the top surface of the specimen. Duals, on the other hand, can detect echoes before transmission is complete due to the electrical and acoustical separation of transmitter and receiver elements. Thus, even on smooth materials a dual of a given frequency may have better near surface resolution than a single element transducer of the same frequency. In many cases, duals will effectively

combine the penetration of lower frequencies with the near-surface resolution of a higher frequency single element transducer.

- Duals reduce the effects of direct back-scattered noise in coarse grain materials such as castings. The spatial separation of transmitter and receiver elements means that each interrogates different volumes of the test material. No noise will be detected from scatter sources that lie outside the region of intersecting beams.
- Duals can be used effectively at high temperatures, since the piezoelectric transducer element can be insulated from surface heat. High temperature duals avoid the nuisance of multiple delay line echoes that appear with single element high temperature delay line transducers.
- At low temperatures, duals avoid the problem of backing echoes that frequently appear when single element transducers are chilled.
- Duals are generally not recommended for measurement of very thin materials (under .040"/1 mm) with flaw detectors, for precision thickness gaging requiring accuracies of +.001" or better, or for certain nearsurface flaw detection applications where high frequency single element contact transducers may be preferable.

Panametrics Accuscan Duals:

Panametrics Accuscan duals are grouped into three series: Fingertip Duals, Widescan Duals, and the new Extended Range Duals. A complete list of available frequencies, element sizes, and roof angles may be found below.

The design of Panametrics duals incorporates a high degree of acoustic and electrical isolation between the transmitting and receiving elements. This permits use of extremely high receiver gain to detect a small leading echo representing a small nearsurface defect or the minimum wall thickness of pitted, corroded metals. Sound barrier materials are carefully selected to make this measurement possible without crosstalk interference from the transmitter side of the dual.

Accuscan duals employ polyimide delay lines for extended service life and high temperature test capability. Accuscan duals with frequencies of 5MHz and lower may be used in intermittent contact on hot surfaces up to 800oF/425oC. Standard 7.5MHz and 10MHz duals can be used in intermittent contact up to 350oF/175oC.

Duals in the "Fingertip" series have a standard 8 deg roof angle with two D-shaped elements in a small round case. Fingertip duals incorporate a high strength, flexible potted cable with internal anchoring for long service life.

"Wide Scan" duals also have a standard 8 deg roof angle with rectangular elements in a squared case. Wide Scan duals offer a larger scanning index than round duals, permitting more rapid examination of large areas. They have microdot connectors for cable attachment.

"Extended Range" duals utilize a variety of shallower roof angles (3.5 deg, 2.6 deg, 1.5 deg, and 0 deg) to provide greater depth of focus and thus greater sensitivity to flaws or backwall reflectors in the range of 0.75"/19mm and beyond in steel.

FINGERTIP DUALS

Frequency	Element Size	Part Number
1.0 MHz	0.50"	D703-RP
2.25MHz	0.75"	D705-RP
"	0.50"	D706-RP
"	0.375"	D771-RP
3.5 MHz	0.75"	D781-RP
"	0.50"	D782-RP
"	0.375"	D783-RP
"	0.25"	D784-RP
5.0 MHz	0.75"	D708-RP
"	0.50"	D709-RP
"	0.375"	D710-RP
"	0.25"	D711-RP
7.5 MHz	0.50"	D720-RP
"	0.25"	D721-RP
10.0 MHz	0.50"	D712-RP
"	0.25"	D713-RP

NOTE:
All Fingertip Duals are provided with a right angle potted cable 6 feet in length, with BNC Connectors. Element diameter refers in a general way to an imaginary transducer element that is made up of the two halves of the dual.

WIDESCAN DUAL TRANSDUCERS

Frequency	Element Size(inches)	Part Number
1.0 MHz	0.50 x 1.00	D741-RM, D741-SM
2.25MHz	0.50 x 1.00	D743-RM, D743-SM
"	0.50 x 0.50	D744-RM, D744-SM
3.5 MHz	0.50 x 1.00	D746-RM, D746-SM
"	0.50 x 0.50	D748-RM, D748-SM
5.0 MHz	0.50 x 1.00	D750-RM, D750-SM
"	0.50 x 0.50	D751-RM, D751-SM
7.5 MHz	0.50 x 0.50	D753-RM, D753-SM
10 MHz	0.50 x 0.50	D755-RM, D755-SM

NOTE:
"RM" part numbers indicate right angle microdot connectors. "SM" part numbers indicate top mounted microdot connectors. Element size refers in a general way to an imaginary transducer element that is made up of the two halves of the dual.

EXTENDED RANGE DUALS

Frequency	Element Size	Roof Angle	Part Number
2.25MHz	0.50"	0 deg	D7071
"	0.50"	1.5 deg	D7072
"	0.50"	2.6 deg	D7074
"	0.50"	3.5 deg	D7073
"	1.00"	0 deg	D7079
5.0 MHz	0.50"	0 deg	D7075
"	0.50"	1.5 deg	D7076
"	0.50"	2.6 deg	D7078
"	0.50"	3.5 deg	D7077
"	1.00"	0 deg	D7080

NOTE:
All Extended Range duals are supplied with a right angle potted cable 6 feet in length, with BNC connectors.
Element diameter refers in a general way to an imaginary transducer element that is made up of the two halves of the dual.

Panametrics Microscan Duals:
Microscan duals are primarily designed for use with Panametrics Ultrasonic Corrosion Gauges, Models , 26DL, 26DL PLUS, 26MG, 26MG-XT and 36DL PLUS With these gauges they may measure remaining metal thickness down to .020"/0.5 mm(using a 10MHz transducer). Microscan duals are available in both high temperature and ambient temperature models, in both standard and low-profile cases. Because specific Microscan duals must be used with specific gauges, consult the Panametrics NDT Sales Department for further information.

Step Block Response:
Typical step block sensitivity curves for Panametrics Accuscan duals are included with this Application Note. A Step block sensitivity curve can be obtained by plotting the amplitude of the first backwall echo reflected from a steel reference block versus a scale of distance or thickness. On steps that are of smaller thickness than the pseudofocal distance, multiple echoes will appear. Only the peak associated with the first back echo is the relevant backwall indication. The other peaks, even if larger, represent mode converted shear wave echoes and multiples of longitudinal wave echoes.
In general, for duals of a given roof angle, an increase in diameter provides a longer pseudofocal distance and an increase in the range of thickness over which echoes of a given amplitude are received. For duals of a given diameter, changes in roof angle produce significant changes in the

pseudofocal distance and the shape of the response curves. The selection of an optimum dual for a given application will be based on specific requirements for resolution and penetration. For assistance, consult Panametrics NDT Sales Department.

V-Path Correction:

For thicknesses greater than approximately .125"/3 mm, thickness or distance calibration for flaw detectors and other instruments using duals follows the same method used for single element delay line transducers. However, for thicknesses or distances below .125"/3 mm, the pulse-echo transit time is no longer linearly proportional to thickness due to the V-shaped path that the sound pulse travels. (*Figure 1*)

The deviation from linearity is shown schematically in *Figure 2*. If thickness or distance measurements are to be made over a limited range near the thin end of the scale, it is possible to calibrate the flaw detector to be approximately accurate over the limited range. However, this thickness/distance calibration will be substantially in error on thicker sections.

If a wider range of thicknesses is to be measured, it may be preferable to calibrate the instrument at the high end of the range and establish empirical corrections for the very low end. Consult ASTM Standard Practice E797 for further information on measuring thicknesses or distances with duals.

Panametrics Ultrasonic Corrosion Gauges, Models 26DL, 26DL PLUS, 26MG and 26MG-XT perform the required nonlinear corrections electronically and automatically, so that correct digital thickness measurements may be made over the entire specified range of the instruments.

High Temperature Measurements:

All of Panametrics standard Accuscan duals are suitable for high temperature measurements. Accuscan duals of 5MHz or lower frequencies may be used in intermittent contact with surfaces up to 800oF/425oC. Accuscan 7.5MHz and 10MHz duals may be used in intermittent contact up to 350oF/175oC.

In making high temperature measurements (above 125 deg F/50 deg C), remember that the transducer elements themselves must be protected from extreme heat. While the delay line materials used in Accuscan duals are good thermal insulators, continuous exposure to very high temperatures will eventually cause heat to reach and possibly damage the transducer elements. Thus, at elevated temperatures use only enough contact time with the hot surface to obtain the required reading. (The Peak Memory function of Panametrics EPOCH flaw detectors is very helpful in recording flaw indications with minimum contact time). A typical duty cycle for temperatures from 200 deg F to 800 deg F is ten seconds maximum surface contact followed by one minute of cooling in air.

It is possible that zero offset, amplitude calibration, and metal path distance measurement will all drift somewhat as the transducer assembly heats up. This is because all delay line materials exhibit some variation in sound velocity and attenuation with large temperature changes. For maximum accuracy, initial calibration should be done with the same couplant used in testing, on reference standards whose temperature is within 25 deg F/14 deg C of the test piece. Calibration should be verified periodically during testing so that any drift may be corrected.

Note:

Panametrics Microscan duals D790 and D791 use a special delay line material with excellent thermal stability, which makes them less susceptible to thermal drift than many other duals.

Panametrics offers two types of high temperature couplants for testing above 200 deg F. Panametrics Medium Temperature Couplant F can be used from ambient temperature up to 650 deg F.

Panametrics High Temperature Ultratherm Couplant E may be used from approximately 500 deg F to 1000 deg F. Be sure in all cases to use enough couplant to maintain good sound coupling, especially since all couplants will begin to boil off as the upper limit of their temperature range is approached. For further discussion of high temperature testing with duals, consult ASTM Standard Practice E587-82.