PIPELINE INSPECTION UTILIZING ULTRASOUND TECHNOLOGY: ON THE ISSUE OF RESOLUTION

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ABSTRACT:

Today, in-line inspection tools are used routinely to assess the integrity and fitness-for-purpose of high pressure pipelines. Ultrasound technology provides the means to obtain quantitative, highly accurate and reliable inspection data for pipelines.

In addition, advancements in electronic design have led to marked enhancements regarding axial and depth resolution. Combined with higher speed capabilities than previous generations of ultrasound tools, this has significantly extended the range of application, offering quantitative and high accuracy data for defect geometries not previously covered.

This paper will focus on and discuss the issue of resolution.

IN-LINE INSPECTION

Today, the use of in-line inspection tools is a standard procedure for the collection of pipeline data required for integrity assessment and fitness-for-purpose studies. Their major task is to provide accurate geometric information regarding the length, width, depth, orientation and location of a flaw. The major advantage of in-line inspection tools is their capability to survey the entire pipe circumference whilst the pipeline remains in operation. They are usually pumped through the line to be inspected (i.e. free-swimming tools) and do not require their own drive.

APPLIED TECHNOLOGIES

Various non-destructive testing methods are applied, each with particular advantages and disadvantages based on the physical principles used. The major technologies are:

- Magnetic Flux Leakage Technology
- Ultrasound Technology
- Eddy Current and Pulsed Eddy Current Technology

A comprehensive overview regarding the capabilities of magnetic flux leakage and ultrasound tools can be found in [1], although it must be noted that some comments regarding the use of ultrasound tools in thin pipe and for the detection of pitting corrosion do not apply to the latest generation of tools available on the market today. Eddy current technologies are not widely used in free swimming tools today.

ULTRASOUND: THE PRINCIPLES

Ultrasound is a non-destructive testing technology which has been applied for a variety of inspection tasks for many years now. A major advantage of ultrasound is the ability to provide quantitative measurements. This means that the actual wall thickness of a pipe section can be determined with high accuracy and reliability. The reporting accuracy regarding depth measurement for the latest generation of tools is around ± 0.4 to 0.5 mm. The highest possible resolution that can be achieved today is 0.06 mm. Usually thresholds for depth measurement of metal loss or cracks are set at 1 mm, however lower thresholds are possible.

There are different ways, using different types of transducers, how the ultrasound principles are applied technically, for instance piezo-electric transducers or transducers based on electro-magnetic acoustic transmission. The most widely used tools available from several vendors make use of piezo-electric transducers.

Figure 1 shows the principle applied for wall thickness measurement. This principle is used for the detection and sizing of metal loss features, such as corrosion or gouging and also for the quantitative wall thickness measurement. An added benefit is the ability to detect and identify mid-wall flaws such as laminations and inclusions and also certain categories of material separations and voids, such as HIC (hydrogen induced cracking).

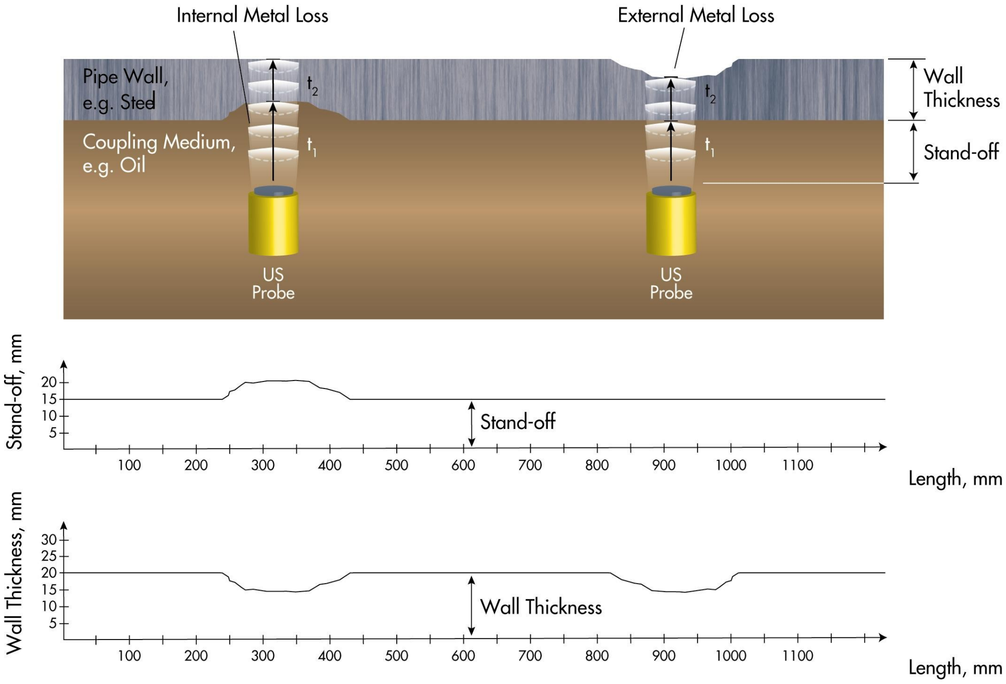

Figure 1: Ultrasound Principle Wall Thickness Measurement

The important issue is that the sensors (transducers) are aligned at right angles to the wall to be inspected. The transducers used are operated in an impulse-echo mode, with other words they act as transmitters and receivers of the acoustic wave used for the measurement. The type of transducer chosen (i.e. dynamic range, focal point etc.) and the characteristics of the electronics used (i.e. pulse repetition frequency, sampling rate etc.) have major influence on the detection threshold, the accuracy and depth and length resolution.

Ultrasound further constitutes the only reliable technology currently available for the detection and sizing of cracks in pipelines.

Figure 2 depicts the crack inspection principle. Here the probes are placed not at right angles to the wall. The sensor carrier design must rather ensure that the incident ultrasound signals are refracted in a manner that they will propagate under 45º inside the pipe.

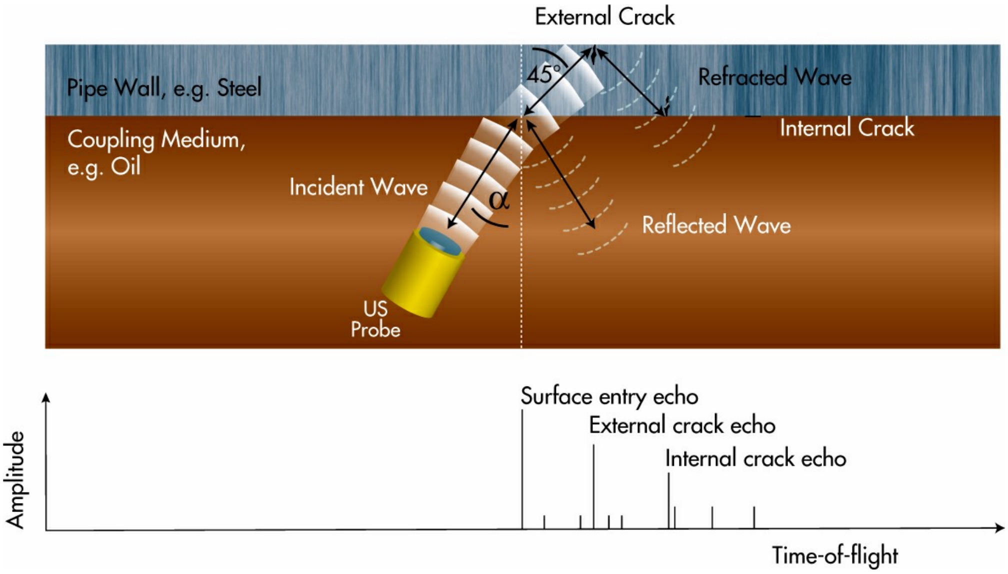

Figure 2: Ultrasound Principle Crack Inspection

Ultrasound tools are ideally suited for the inspection of thick wall line pipe, as often found in offshore pipelines. Wall thicknesses of up to 50 mm can be inspected with the same specifications as thinner wall.

THE ULTRASONIC IN-LINE INSPECTION TOOL

Figure 3 shows the layout of a typical ultrasonic tool. The batteries needed for the energy supply and the electronics used, e.g. for controlling the ultrasound sensors and recording data, are housed in pressure vessels. A trailing sensor carrier always houses enough sensors to ensure full circumferential coverage of the pipeline being inspected. The pressure vessels and the sensor carrier are connected via universal joints to ensure that the tool can also negotiate bends. Odometer wheels are used for distance measurement.

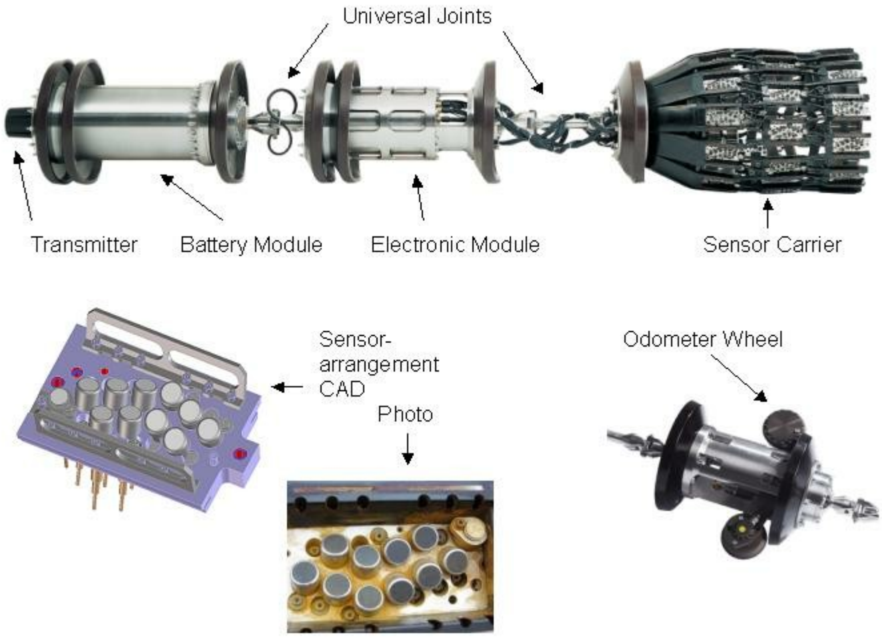

Figure 3: Layout of an ultrasonic in-line inspection tool (crack detection)

METAL LOSS INSPECTION

Metal loss inspection encompasses finding and accurately sizing flaws and wall thickness losses due to corrosion or gouging. The data obtained, e.g. length, depth, width etc., are then used for integrity assessment, corrosion growth assessment or the determination of service intervals.

All measurement principles have specific characteristics regarding their accuracy and error margin. The better the accuracy and the more reliable (less errors) the method, the better the suitability for use in any integrity assessment work. An important factor here is the confidence level. The confidence level quoted for ultrasound technology is usually 95%, compared to an average value of 80% for magnetic flux leakage.

Accuracy of magnetic flux leakage tools is usually around 10% of wall thickness, although there are some tools available that quote a 5% accuracy regarding the detection of internal flaws. For an average onshore line, assuming an 8 mm wall, this would translate into ± 0.8 mm. For an offshore line with, say a 3/4 inch wall (19 mm) this already translates into ± 1.9 mm. The quoted reporting accuracies, i.e. stated depth measurements in a final report for ultrasound tools is usually in a range of ± 0.4 to 0.5 mm, depending on the vendor and tool used. Depth resolutions are usually in the order of 0.1 to 0.2 mm. With the latest technology ultrasound tools depth resolutions of 0.06 mm can be achieved. Regarding the detection, sizing and comparison of flaws based on corrosion or grooving, this is a major advantage of tools utilizing ultrasound technology.

Another advantage is owed to the fact that ultrasound tools can quantitatively measure the contour of a metal loss flaw. This implies that the "shape" of the bottom of a corrosion or gouge can be measured, a true river bottom. This is an added advantage for higher degree maximum allowable pressure calculations, such as RSTRENG or calculations based on the DNV code. This technical ability also provides for the option to use the geometric data provided as input for the modeling of a mesh for Finite Element Calculations.

Figure 4 shows the contour of a metal loss flaw and the difference in resolution achieved by improving the resolution from 0.2 mm to 0.06 mm.

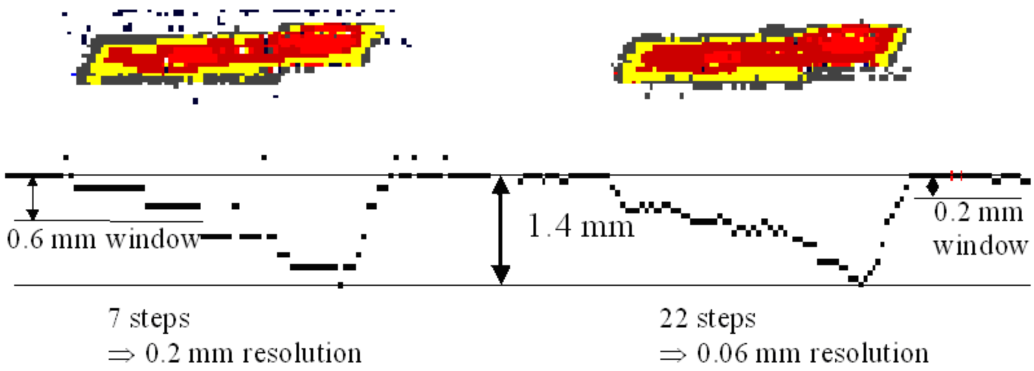

Figure 4: Effect of improving depth resolution

QUANTITATIVE WALL THICKNESS MEASUREMENT

The advantage of quantitative wall thickness measurement is the ability to provide an accurate value for local wall thickness. The quality of data from modern ultrasonic tools is such that they can also be used for quality inspection purposes, i.e. comparing actual with nominal wall thickness. Such data is also of value regarding base line surveys, sometimes also referred to as "finger printing". The data obtained during such an inspection constitutes a reference for further inspection runs. It is clearly advisable that a reference should be of the highest possible accuracy and reliability otherwise readings obtained from consecutive inspections and their comparison with the original data will only be of limited use.

Another application which is becoming more popular is related to the uprating of pipelines. Transportation demand is increasing and the construction of new pipelines is a complex and costly process. It is therefore an interesting option to see whether the throughput can be increased for a given line by increasing the operating pressure. However, this directly implies that it must be proven that the pipeline can withstand the resulting increased stresses, which in turn requires knowledge of the true local wall thickness actually existing at every point in the line. The accuracy requirements for this approach are usually even higher than for metal loss inspections. The accuracy aimed for is ± 0.1 mm.

RESOLUTION: A THREE-DIMENSIONAL ISSUE

The term resolution is most widely used in relation to depth measurement, as touched on in paragraph 4 above. However, it has to be noted that resolution is an issue in all three dimensions, e.g. depth resolution, axial resolution and width resolution.

Depth Resolution

The depth resolution of an inspection tool indicates which precision the depth measurement can achieve. It is not to be mistaken with the depth sizing accuracy, which is a value defined by the operator of the tool and which is usually stated in the defect specification sheet. The depth resolution is primarily set by the design of the inspection tool and is influenced by the sensor technology and electronics design. The better the resolution an inspection tool can achieve the greater its ability to precisely measure the depth contour of a given flaw or defect. A good example is the river bottom profile of a corrosion as shown in figure 4.

Axial Resolution and Circumferential Resolution

Measurements taken by an in-line inspection tool basically also supply a grid of measurements taken, i.e. measurements taken along the axis of the pipe inspected and measurements taken across the circumference of the pipe. Figure 5 depicts such a typical grid.

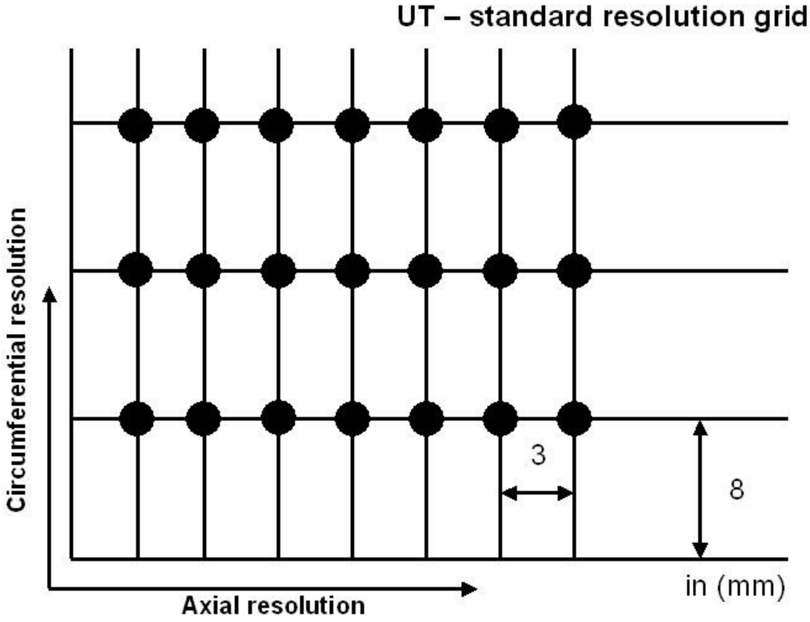

Figure 5: Standard resolution for an ultrasonic in-line inspection tool

Here, the axial and circumferential resolution is shown. The axial resolution of 3 mm is determined by the pulse repetition frequency of the tool and the speed range in which the tool operates. The number of measurements taken is influenced by the speed at which the tool travels and the way the sampling rate of the tool is controlled, i.e. the issue of speed triggering and time triggering. The circumferential resolution is determined by the sensor carrier design, which in turn determines the sensor spacing. Putting it simply, this implies that the more sensors placed across the circumference, the higher the circumferential resolution. In a standard resolution this value is approximately 8 mm. The black circles in figure 5 depict measurement locations (figure does not show area covered by a sensor!). For the area shown in this example 21 readings are taken.

In summary it can be said, however, that as the sampling rate increases and with it the axial resolution, the quality of the data recording will also increase.

As a result, the implementation of higher axial and circumferential resolution increases the refinement of the measurement grid and has a marked effect on data quality and accuracy. This is depicted in figure 6.

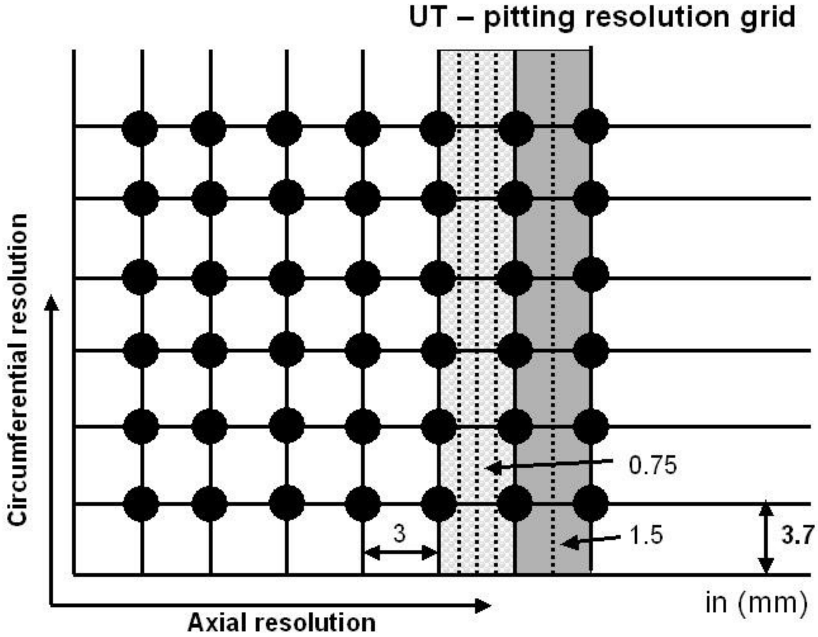

Figure 6: Effect of increased axial and circumferential resolution

The picture shown covers the same area as in figure 5 above. Due to an optimized sensor carrier design typically used for pitting inspection the circumferential spacing of the sensors was decreased to 3.7 mm. The axial sampling can be increased from 3 mm to 1.5 mm (i.e. one reading taken every 1.5 mm along the pipe axis) or even to 0.75 mm. These increased axial resolutions are shown as light grey and darker grey regions in figure 6. The ability to configure the tool for specific inspection requirements means that the resolution, or in other words the refinement of the measurement grid can be varied. In the figured examples this means that the area inspected (the same in figure 5 and figure 6) can be inspected with the following resolutions, see table 1.

axial resolution (mm)	**circumferential resolution (mm)**	**measurement points**
3	8	21
3	3.7	42
1.5	3.7	84
0.75	3.7	168

Table 1: Different resolution configurations and measurement for the given example

These improvements directly translate into advantages (i.e. less measurement error, higher confidence) when the inspection data are used for integrity assessment purposes.

Pitting Inspection

The pitting configuration has been designed due to a requirement to run specialized surveys for corrosion flaws where the depth extent of the flaw is much larger than the surface area. Such a local type of corrosion is usually referred to as "Pitting". For such an inspection requirement several approaches and steps can be taken:

i. using smaller sensors and increasing the number of sensors across the circumference in order to find smaller corrosion flaws. This implies that more channels are needed to record the data, in turn requiring a suitably sized electronics unit.

ii. additionally special transducers with a focused beam can be used .

By applying such an approach, tools can be configured to look for flaws as small as 5 mm in diameter. Utilizing small and focused probes, pitting corrosion with a surface extent as small as 2.5 mm can be detected today.

Figure 7 shows a specialized sensor carrier for pitting inspection.

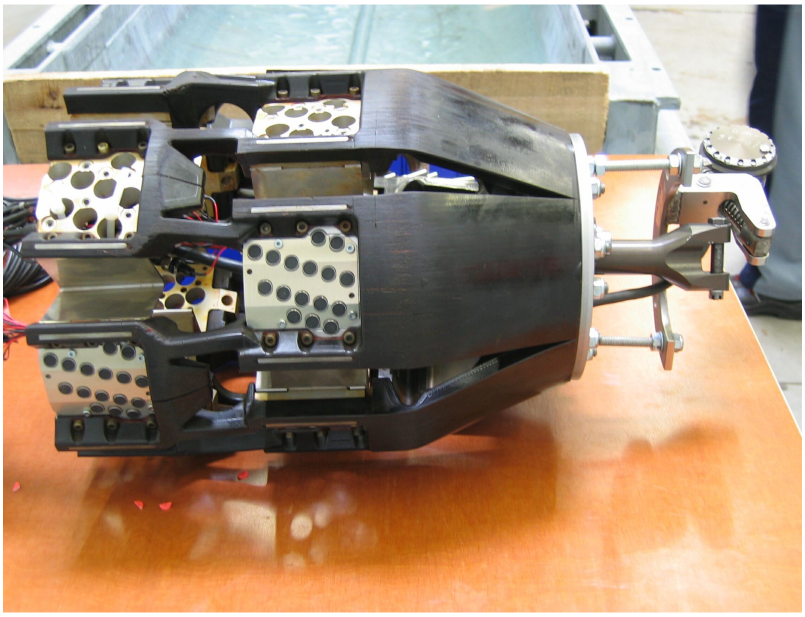

Figure 7: Sensor carrier being prepared for pitting inspection, showing pitting sensors and empty sensor plate of standard size

Figure 8 shows the various UT sensor plate layouts for standard resolution, enhanced resolution and pitting resolution.

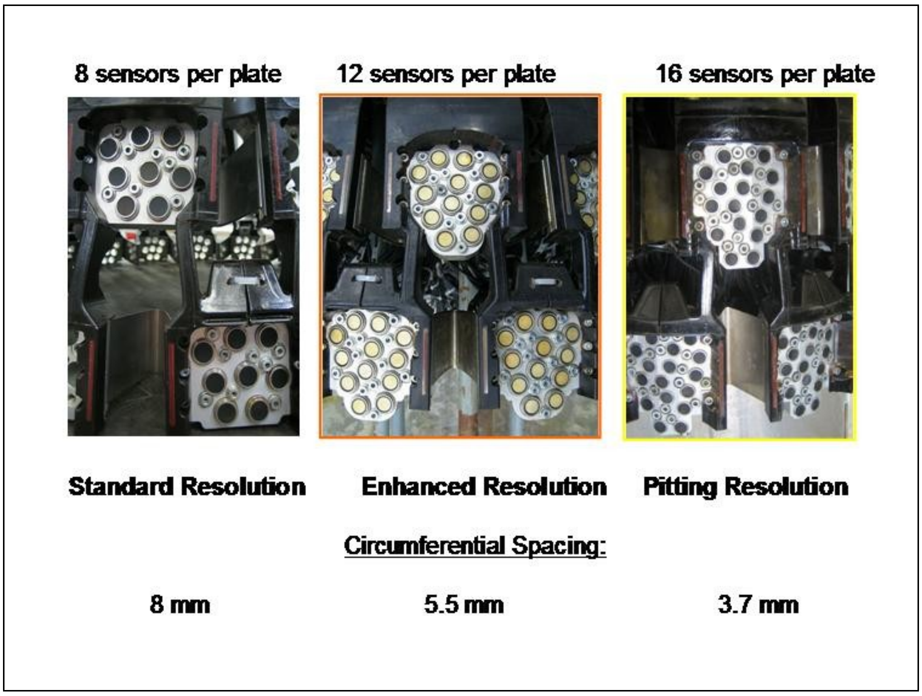

Figure 8: Sensor Plate Layout

CONCLUSIONS AND OUTLOOK

In-line inspection tools utilizing ultrasound technology are widely used today, especially for the inspection of liquid lines. They also offer the only true crack detection capabilities.
An important issue regarding data quality and usability for integrity assessment work is the resolution a tool has. Resolution has to be considered in all three dimensions. Today, specially configured ultrasonic tools are available, incorporating enhanced capabilities regarding depth, axial and circumferential resolutions. These new tools are especially useful regarding the detection and sizing of local corrosion flaws such as pitting corrosion.
The next step is to make the accuracy and quantitative wall thickness measurement capabilities available for gas pipelines, without the need of a liquid couplant. Development work is currently under progress and in-line inspection tools incorporating those capabilities will be available in the very near future.

References

[1] Goedecke, H.; Ultrasonic Or MFL Inspection: Which Technology Is Better For You?; Pipeline & Gas Journal; October 2003; pp. 34-41.