Ultrasonic Inspection of Welds in Nozzles, Nodes, Curved Surfaces & TKY Joints

Contents

Introduction

This is the third in a series of notes related to weld inspection, one of the key applications of non-destructive inspection. They are not intended as a tuition course in how to use the equipment, although a few relevant aspects may be highlighted.

This series currently consists of three documents:

- E008, Ultrasonic Inspection of Welds in Flat Plate.
- E009, Ultrasonic Inspection of Welded Pipes and Tubes,
- E010, Ultrasonic Inspection of Welds in Nozzles, Curved Surfaces and TKY Joints

These notes should be read in sequence; this document is supplemental to the first and second, and assumes the reader is familiar with the other documents.

Further notes will discuss other applications using ultrasonic inspection technology.

Nodes, Nozzles, and Joints - Terminology

The general term covers a huge range of possible weld configurations of joints between various plates and pipes. Different approaches must be taken for each, and often it will be the responsibility of the operator to select and optimize an appropriate inspection configuration - so it is important to understand the terminology we are dealing with.

Corner joints are, broadly, any two pieces of plate metal joined at a non-zero angle. T-joints are two pieces joined such that one butts onto the continuous surface of the other.

Cruciform joints are three (possibly four) pieces joined such that the section resembles a cross.

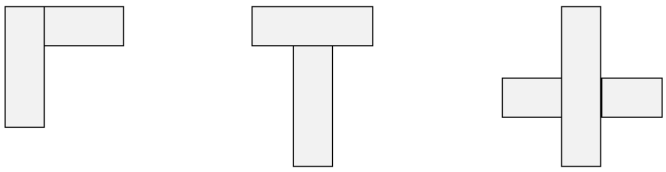

Figure 1 Simple joint shapes

When two (or more) tubular sections are joined together, we describe these joins as **nozzles** where the joining piece is much smaller (typically up to half the diameter) than the main tube, or **nodes** where they are of similar diameter. Nodes may be closed (where the main pipe is not cut, i.e. purely for structural joints) or open to allow fluid flow.

We can describe joints as **set-on** when the joining piece is cut to go outside the main piece or **set-through** when it passes through the piece.

Figure 2 Typical weld preparation (single sided) for set-on and set-through nozzle

A right-angled tubular joint is a T joint; at other angles it is known as a Y joint, and when there is more than one joint at a site as a K joint.as shown in Figure 3.

Nozzles in particular can also be offset from the centre line of the main part, making inspection more complicated. In general, inspection of complex joints requires operators with considerably more experience and additional training compared to simpler welded joints in plates and pipes.

Figure 3 T, K and Y tubular joints.

Corner Joint

The corner joint is very simple to visualize: two pieces of metal come together at right angles. But even with this simple shape, there are many possible configurations of weld. Some typical examples would be as shown in Figure 4.

Typically, the choice of weld configuration will be determined by required characteristics and access, and the choice of inspection approach will be determined by which surfaces can be accessed and by the weld configuration. As always, we want to ensure that the sound beam reaches critical weld geometries at a favourable angle for detection. We must of course also ensure that we inspect for defects within the weld, and for transverse defects.

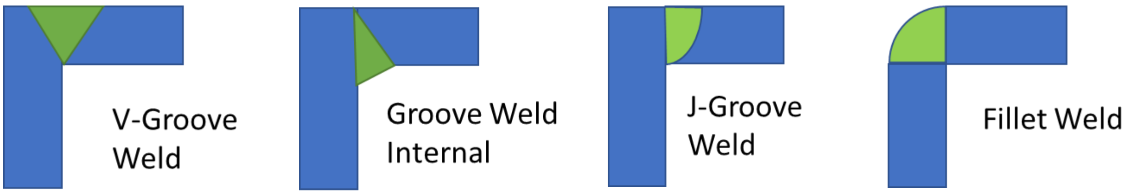

Figure 4 Corner joint: possible weld geometries

As was discussed in the two previous notes, it is desirable to design an inspection such that the sound beam hits the weld preparation at close to 90 degrees. Some thought will show that this is difficult for some of the above configurations. We will discuss each case.

External V-groove weld

The V-groove weld can be inspected easily with suitable choice of preparation angles (a 30-degree shear wave cannot be reliably generated, so 45-degree was chosen for the outside preparation on the outside weld): either from the outside, with the probe in positions B and D, or from the inside, with the probe in positions A and C.

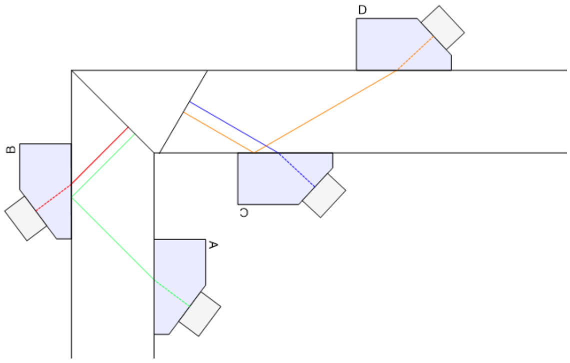

Figure 5 Inspection of V-groove corner weld

Internal groove weld

In the case of the internal weld, only one side of the weld is prepared to an angle. Unless access to the outside is available, any lack of fusion defects on the 90-degree surface may be difficult to find reliably. When the outside can be accessed. any lack of fusion defects can be easily found with a zero-degree probe from the outer surface. It will be necessary to keep precise track of the probe

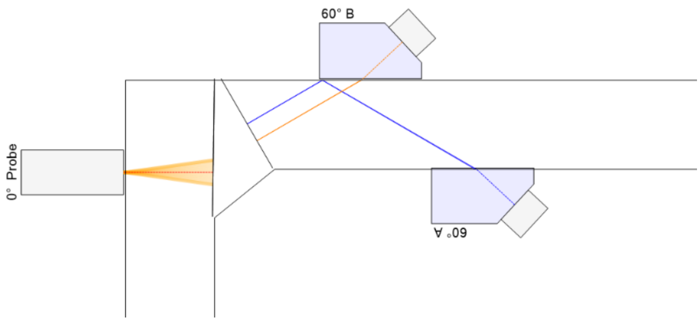

Figure 6 Inspection of corner weld with internal groove.

position, as lack of fusion defects can easily be confused with reflections from the vertical face.

External J-weld

The situation for the external J-weld is similar: again, the 90-degree face can only be easily inspected from the external 'vertical' face.

Because the curved preparation face is not at a constant angle, inspection with a range of sound beam angles is recommended. A phased array sector scan is advantageous here.

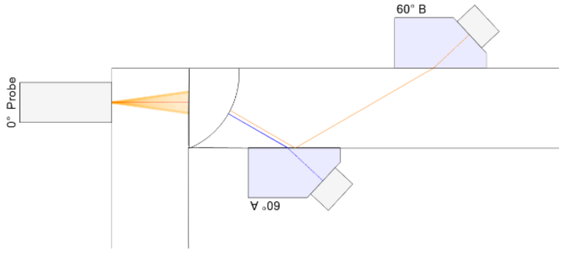

Figure 7 Inspection of J-groove corner weld.

Fillet weld

For the fillet weld, unless the fillet has been ground flat there is no direct sound path that will do this. Fillet welds are generally avoided where the application is considered sufficiently critical to require ultrasonic NDT.

However, where inspection of such a weld is deemed essential, we may be able to use a 'tandem' probe arrangement, where one probe transmits and another receives. In practice this is quite complex to arrange easily, since the two probes have to move independently to cover the full height of the weld. It is worth noting that the latest FMC-TFM phased array equipment provides a good solution for this.

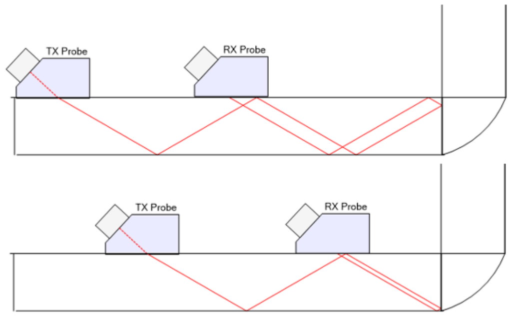

Figure 8 Tandem inspection for perpendicular surface.

Of course, we will also have to use appropriate single probe scans to find other defects within the weld.

T-Joints and 'Cruciform' Joints

These consist of two or three metal plates joined at right angles. The welded joints may be single or double sided.

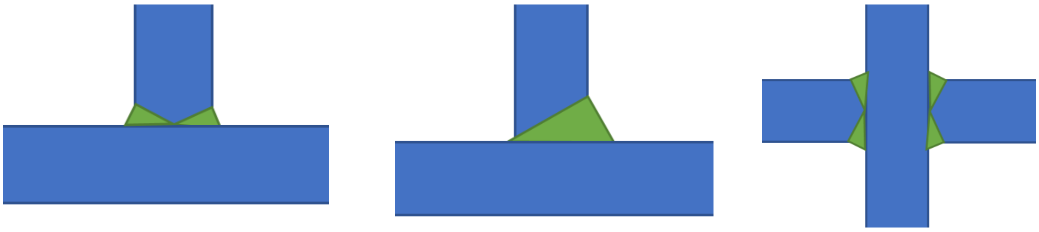

Figure 9 T and Cruciform joints

Again, the requirement is to develop a scanning plan that, where possible, gives full coverage of all possible defect zones within the weld.

In the case of the 'cruciform' joint, it is not possible to scan the fusion faces of the weld with a normal beam probe because the other piece of metal is in the way. Instead, a very shallow beam probe (e.g. 80-degree) should be used, as shown by Probe C in Figure 11

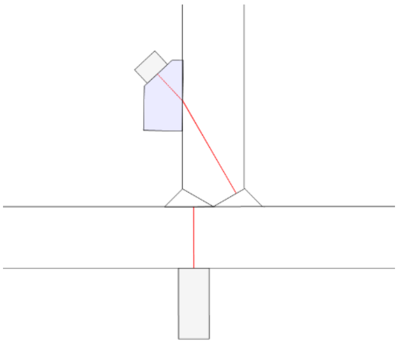

Figure 10 Typical scans for inspection of a T-joint

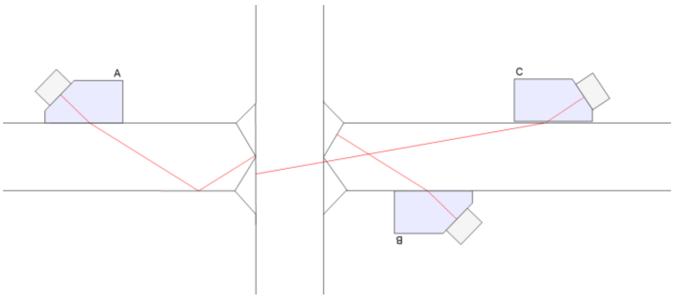

Figure 11 Typical scans for inspection of a cruciform joint

With complex joints of this nature, there are many possible scan directions and angles that can be used. Figure 12 (extracted from BS3923-1:1986) shows possible scanning locations and directions.

The selection of scans used will depend on the size, exact configuration, and service requirements for the joint. In many cases this will be mandated by a customer design specification or an agreed standard.

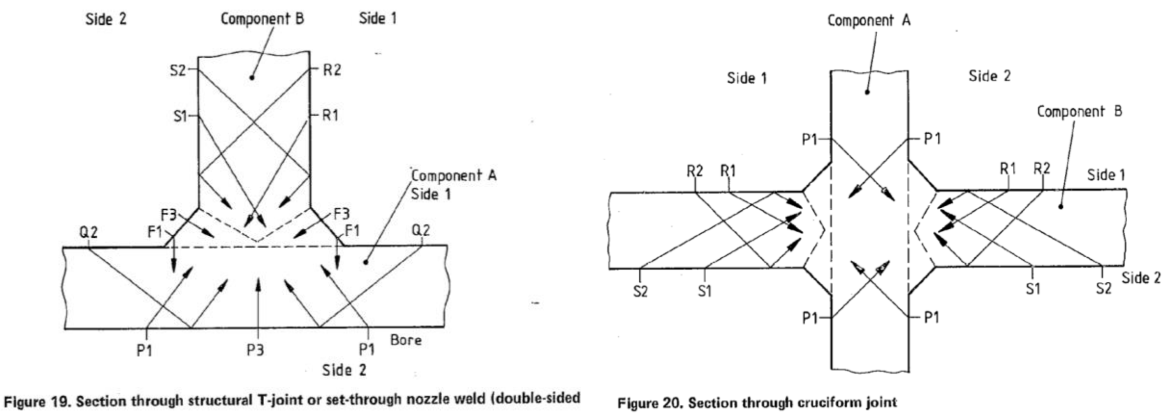

Figure 12 Possible angles for inspection of T and cruciform joints from BS3923-1:1986

The Sonatest WAVE instrument allows the user to model the sound reflection pattern inside a limited range of Corner and T-Joint configurations, as shown in Figure 13 and Figure 14.

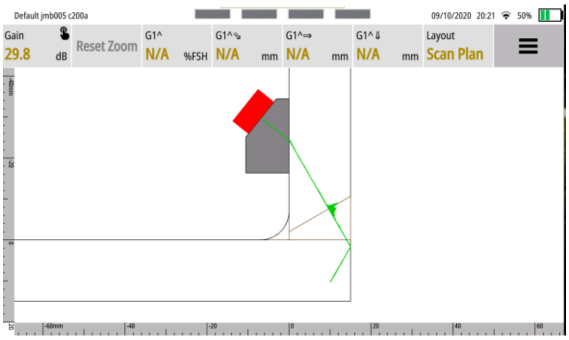

Figure 13 Corner joint on Sonatest WAVE

Figure 14 T-joint on Sonatest WAVE

Scanning with Phased Array Probes

As shown in Figure 15, T and cruciform joints may be scanned with phased array probes, reducing the number of scans required and the need for rastering. Ideally scans from all surfaces should still be carried out: where this is not possible, the extent of any unscanned areas can often be reduced by comparison with mono-element probes, because a wider range of angles is available. Where possible, a suitable scanner should be used.

Again, care is needed in interpreting the results: a few phased array systems allow a complex joint to be modelled, allowing reflections to be fully understood, When this facility is not available an appropriate flat plate representation for each scanning direction can be used with care.

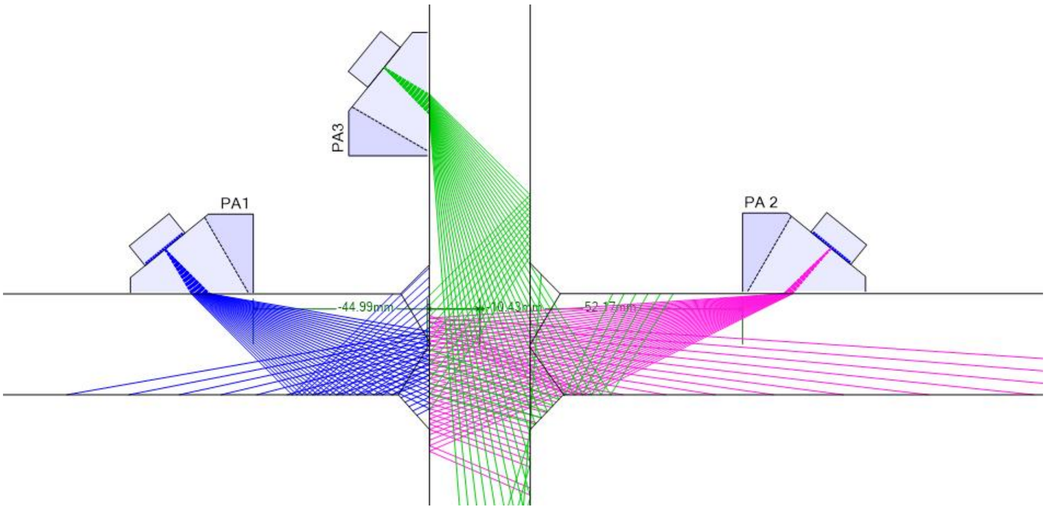

Figure 15 Phased array scans of cruciform joint

Inspection of Tubular Joints

The complexity of ultrasonic inspection of tubular joints results primarily from the changing geometry of the joint as we move along it.

If we take a cross section through a typical arrangement as shown below:

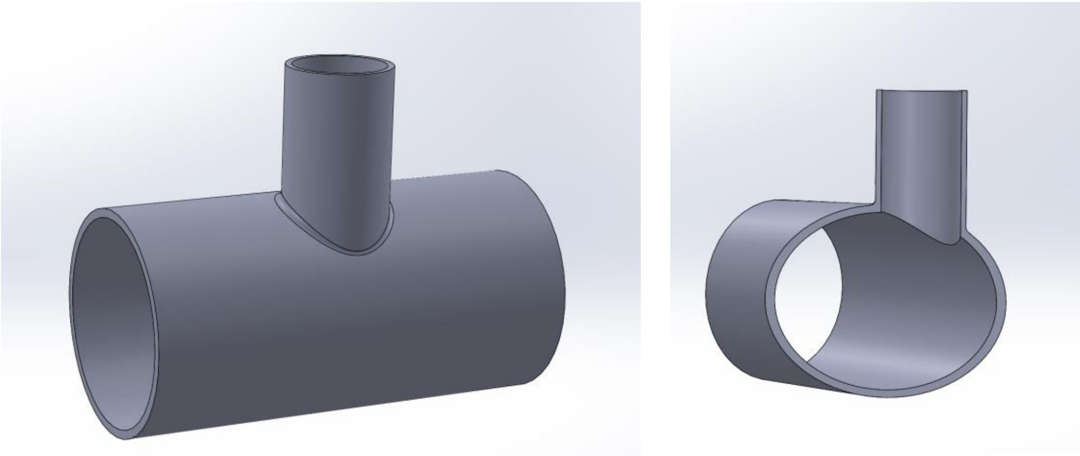

Figure 16 Example Tubular Joint, showing cross section

It is obvious that the geometry on the two sides of the joint is very different – at one side it is close to a right-angle, at the other close to 140 degrees.

The recommended approach is to divide the weld into several zones, as shown in Figure 17. The number of zones selected is a compromise between accuracy and complexity and typically the larger the pipe the more zones will be allocated.

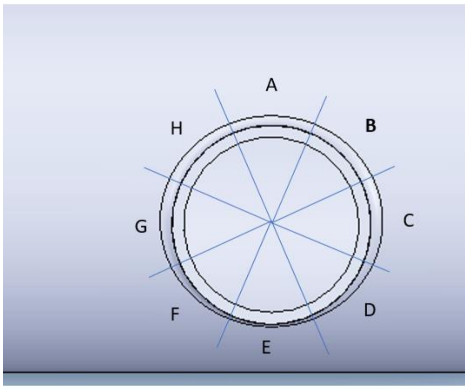

Figure 17 Typical scanning zones for joint

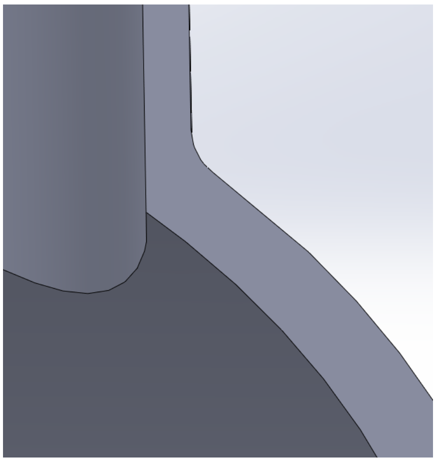

Figure 18 Closeup of 'Zone F' geometry

In this case the pipe exits at 90 degrees, although it is not centred, so zones B & H, C & G, and D & F will have equivalent, although reversed, geometry.

For each zone an appropriate scan plan must be developed, and suitable probe angles and scanning patterns assessed.

Figure 19 shows a scanning approach for zone 'F' (the cross-section shown in Figure 18) It will be noted that some parts of the weld are impossible to insect fully without a probe on the inside of the assembly, and there will be times when this is not feasible.

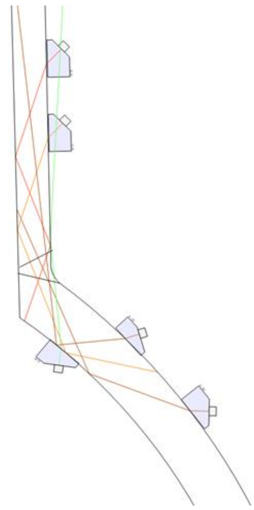

Figure 19 Scan approach for 'Zone F'

Sometimes it is preferable to design the joint with a relatively short 'stub' pipe, allowing access to inspect the joint properly, and then weld on a longer pipe.

In an ideal world, the design of joints will take inspectability into account and ensure that all joints can be fully inspected, whether by ultrasound or some other method. In practice this is not always possible, and the design analysis must consider the possibility of 'undetected defects' and ensure that they are mitigated to the maximum extent possible.

This is a situation where you cannot 'inspect out' problems; in these cases, welder qualification and experience is at least as important as the inspection.

The Sonatest WAVE instrument allows some tubular joint cross sections to be modelled. (Figure 20)

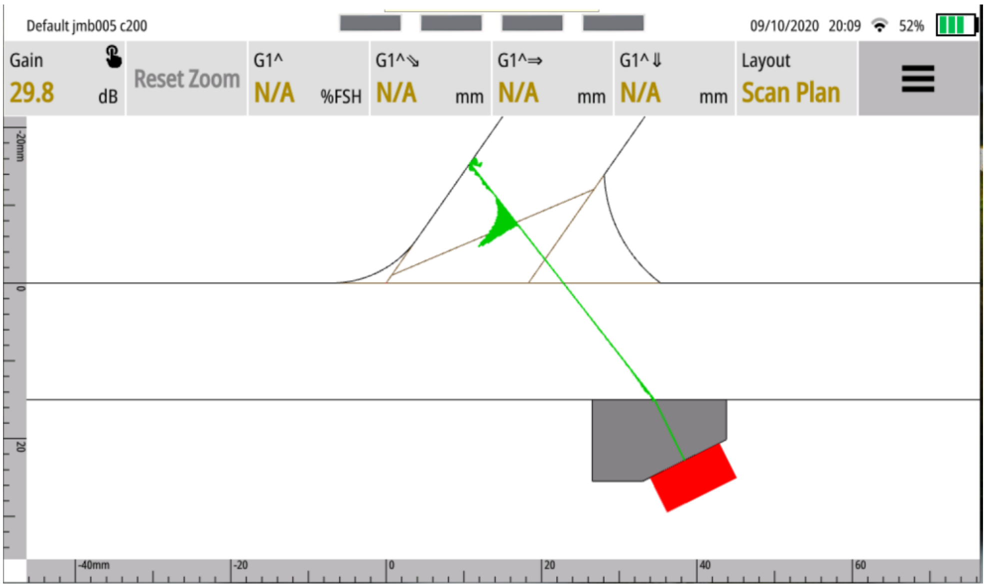

Figure 20 Angled joint simulated on Sonatest WAVE

Tubular Joint Inspection with Phased Array

Techniques for phased array inspection of nozzles are being developed. In concept this is straightforward, but interpretation of defect position can be difficult unless the instrument used is capable of ‘understanding’ the geometry of the structure.

Scanning from a side with a ‘straight’ approach to the weld, will give more easily interpreted results as shown in Figure 23, but obviously this is not always possible.

Again, it will be necessary to vary the probe offset to keep a constant distance to the weld.

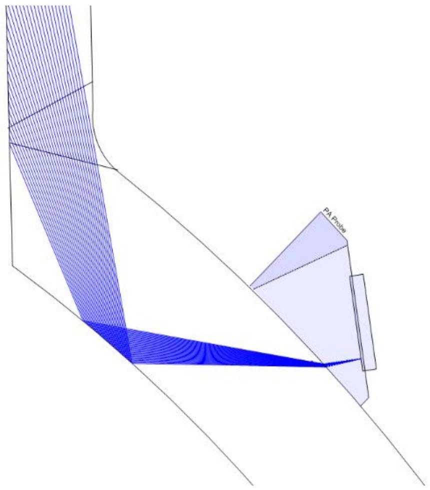

Figure 22 Phased array scan of tubular joint

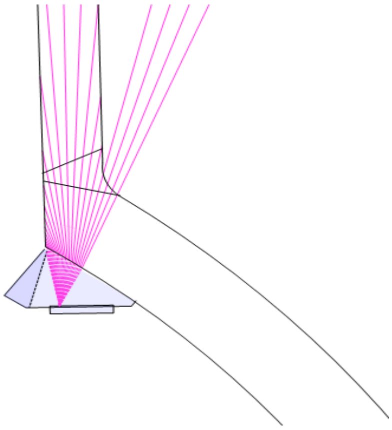

Figure 21 Phased array internal scan

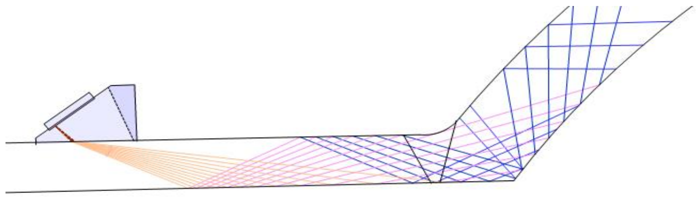

Figure 23 Scan from joining pipe

The scans shown in Figure 22 and Figure 23 will still not give full coverage of the weld zone at an optimal angle, and it may be desirable to access the inside of the assembly as shown in Figure 21

Plotting multiple angles within many tubular joint structures is impractical without specialized software, so ultimately inspection of complex tubular structures is best done using manual mono-element techniques unless phased array equipment with automatic geometry tracking is available.

Some high-end equipment (for example the Zetec TOPAZ system with Ultravision software, shown in Figure 24 allows a CAD model of a joint to be imported; the correct cross section is then selected based on encoder positioning and echoes plotted appropriately. However, it may still be necessary to manually control the offset from the weld.

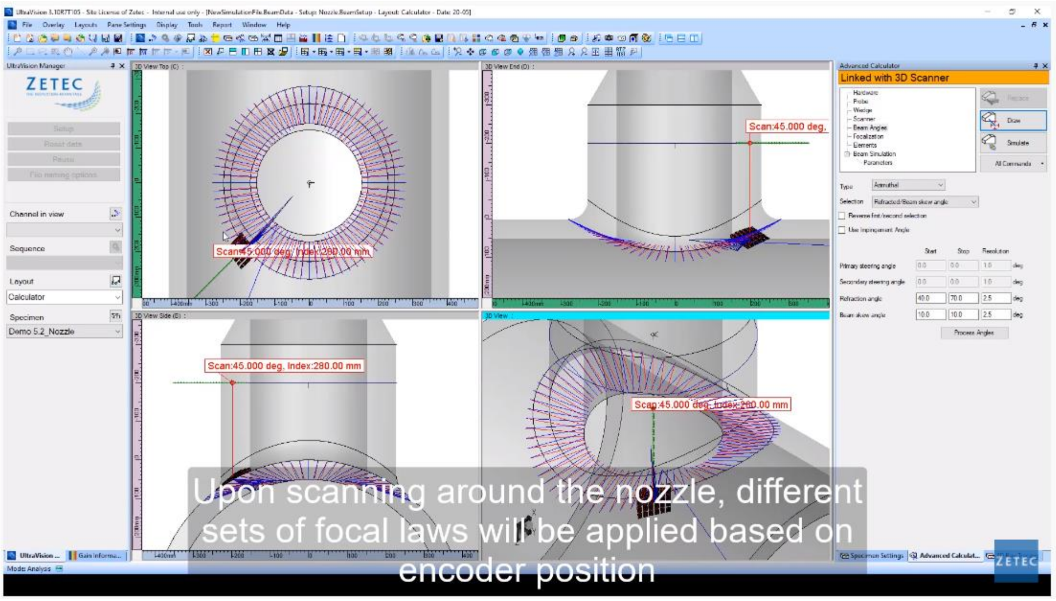

Figure 24 Zetec Ultravision, image from YouTube video.

However, for ‘simpler configurations, particularly straight joints where the joining pipe is significantly smaller than the main one (typically greater than around 5x diameter ratio) approximating the configuration to a pipe welded into a flat plate, a standard phased array setup such as the veo+ can be used very effectively. [i]

In applications where the development cost is justified, it seems likely that fully automated scanning systems, possibly robotic, will be developed in future.

Scanners

Scanning systems to enable probe tracking and recording of results from Nozzle scans are available, for example, Phoenix produce the NozzleScan, and a version of the Jireh Rotix configured for nozzle inspection is available, These have movement in three axes with encoders to track the probe position.

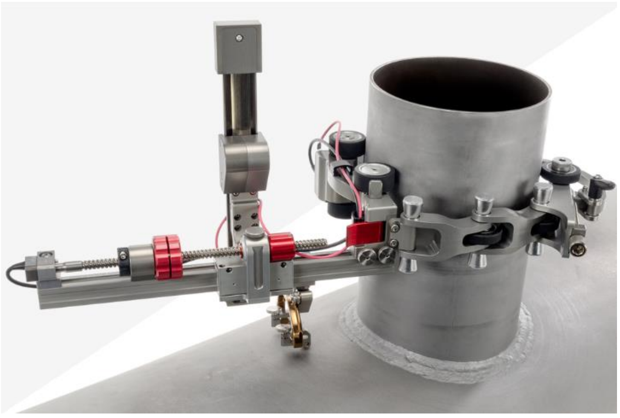

Figure 25 Jireh Rotix 3-Axis nozzle scanner.

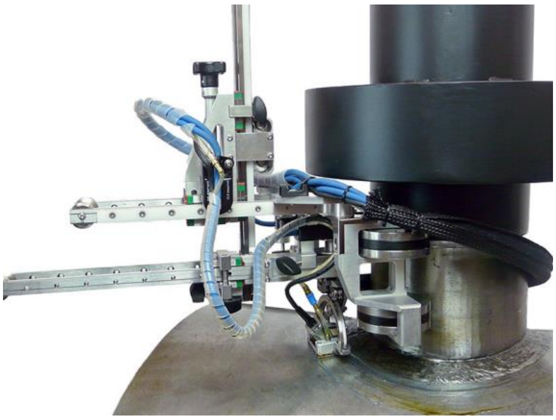

Figure 26 Phoenix NozzleScan

References

Inspection of welded steel joints is covered by ISO 17640-2018, The obsolete British standard BS3923-1:1986, which it replaces, does give significantly more guidance detail on various geometries and may be helpful as a reference.

Images within this document were produced using the Eclipse BeamTool software.

---

[i] "Inspection of Nozzles using the Veo+ and Phoenix Nozzle Scan", Sonatest educational note

