Ultrasonic Inspection of Welds in Tubes & Pipes

Contents

Introduction

This is the second 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 Welds in Tubes and Pipes
- E010, Ultrasonic Inspection of Welds in Nozzles, Nodes, Curved Surfaces & TKY Joints

These notes should be read in sequence. This document is supplemental to E008, and assumes the reader is familiar with it.

Further notes will discuss other applications using ultrasonic inspection technology.

Pipe technology - types of pipe

Steel pipe can be manufactured using a variety of processes. All of these have different trade-offs in terms of feasibility, cost, and quality.

Seamless

The highest quality pipe is made using a seamless process which avoids the weaknesses associated with an unnecessary weld. Most commonly, a billet is heated and then forced over a mandrel. This is then rolled to the desired diameter. Further processing, such as cold drawing, is then used to produce smaller diameter pipes. Seamless tubing is typically only feasible up to a limited diameter, typically of the order of 20-30 centimetres, depending on the process and the initial billet diameter.

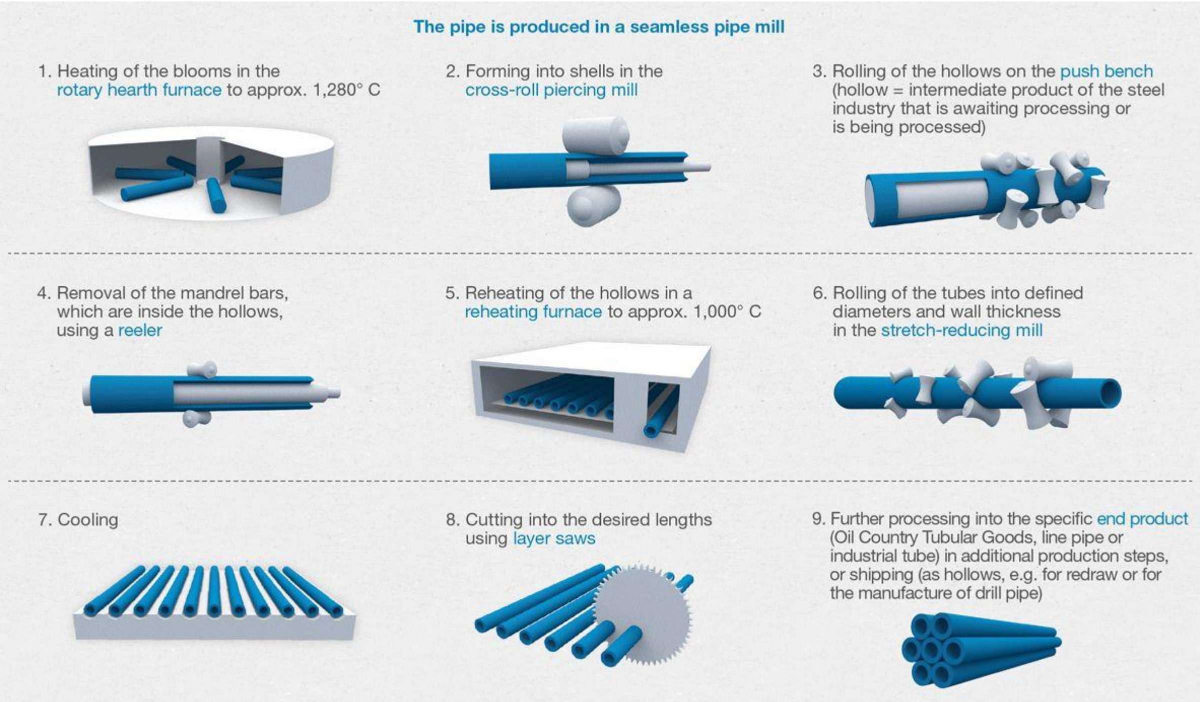

Figure 1 Manufacture of seamless tube (Voestalpine)

Longitudinal seam welded – ERW, SAW

Lower cost tubing is typically made by forming a steel strip into a U-shape, and then further into a circle; this can then be welded using a variety of processes.

Economical mass production of thin-wall steel tubing for many purposes is made using electric resistance welding or high-frequency induction welding. Both are commonly referred to as 'ERW' tubes. The strip edges are forced together and passed through a welding station, where an electric current is applied either directly or via an induction coil which causes a circulating current. This heats the joint, which is then trimmed and rolled to the final size. This can produce relatively high strength tubing, which is typically tested in line using either eddy current or ultrasonic techniques.

For thicker materials, a submerged arc welding (SAW) process is used. This process requires ultrasonic testing.

Spiral welded pipe
Spirally (or helically) welded pipe is manufactured by welding steel strip together at an appropriate angle to give the required diameter. One of the advantages of this process is that the pipes are slightly stronger, because internal pressure stress during use is distributed along the weld rather than pulling it apart. The spiral welding configuration is very suitable for making large diameter steel tubes of relatively thin wall thickness.

It has the particular advantage that steel strip of a fixed width can be used to manufacture a variety of pipe diameters by choosing the appropriate angle – whereas steel strip for longitudinal pipe, once cut, can only be used for a given diameter pipe. This makes spiral welding much more flexible. One disadvantage is that the weld for a given pipe will be longer, and thus the costs associated with welding and inspection will be greater.

Figure 2 Spiral and longitudinally welded pipes.

Pipe sizes
For historical reasons, small diameter pipes are is commonly referred to by their 'nominal size'. The actual size is significantly larger than might be assumed. For example, a 'quarter-inch' pipe is actually 13.7 mm (0.54 inches) in outside diameter, while a 'one inch' pipe is 33.4mm (1.315 inches). The wall thickness of the pipe does not affect the OD. Above 12 inches, sanity prevails, and the 'nominal size' and actual outside diameter are the same. Pipes are commonly referred to by their 'schedule weight'. For full details, refer to the table in Appendix A.

Ultrasonic inspection of pipes

Girth welds

Girth welds, or circumferential welds, are used to join two sections of pipe together or to join sections of pipe to elbows, flanges or other fittings.

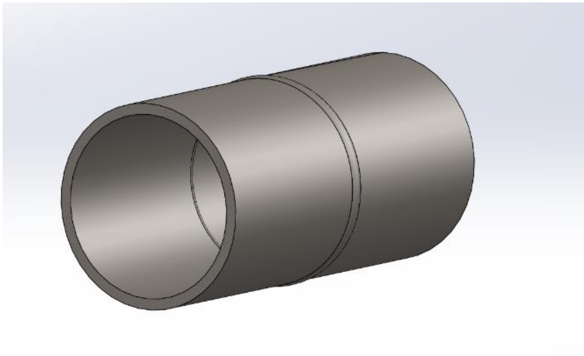

Figure 3 Girth weld

From an ultrasonic perspective, girth welds are very similar to butt welds in in flat plates. When inspection is carried out across the weld, the ultrasonic path is not affected by the curvature of the pipe; however, for small and medium diameter pipes, a shaped wedge (Figure 5) to fit the curvature of the pipe should normally be used. [Tip: The free ESWedgeGap software Figure 8 can be used to confirm an acceptable fit for wedge and pipe diameters.]

Inspection can be done using mono-element, phased array or TOFD methods as discussed in education note E008. The beam can be considered to pass primarily through the centre of the wedge, so calculation will assume the height at the centre.

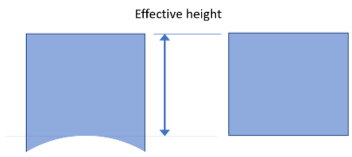

Figure 4 Effective height for shaped wedge

Use of a suitable scanner to keep the probes movement parallel to the weld is pretty much essential. These will be discussed later.

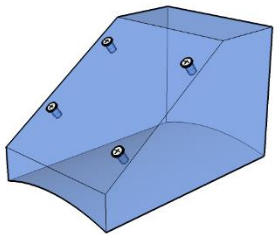

Figure 5 Wedge with axial curvature

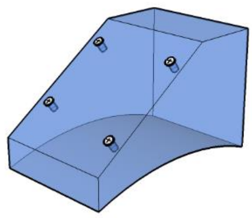

Figure 6 Wedge with circumferential curvature

Figure 7 ROTIX scanner for girth welds (shown without probes for clarity)

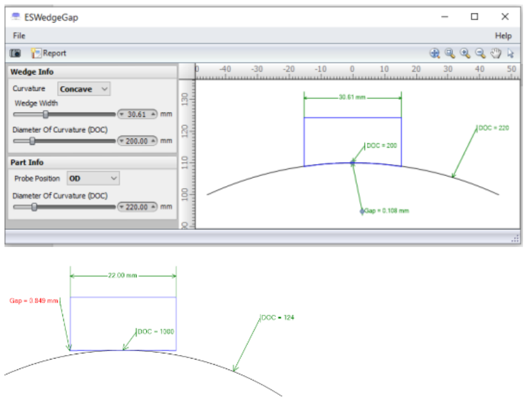

Figure 8 ESWedgeGap software

Longitudinal welds

While in many cases the pipe seam welds will have been tested during manufacture, it is often required to confirm or repeat this at the fabrication stage.

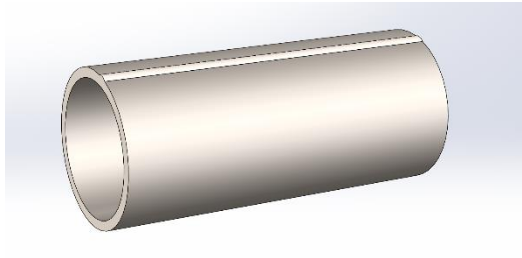
Figure 9 Longitudinal weld

Ultrasonic inspection of longitudinal welds introduces several extra complexities:

1. Other than on the largest diameter tubing, it will be necessary to use a wedge that is shaped to fit the curvature of the pipe (as shown in Figure 6);
2. The incident angle on the weld will vary, depending on the distance between the weld and the probe;
3. For phased array inspection, the focal law calculation is significantly more complex;
4. With TOFD, the shortest path between the two probes is no longer along the surface.

Looking at these in detail:

Wedges

Because the curvature corresponds to the 'long edge', matching the wedge to the pipe diameter is critical.

For example, for an 18-inch pipe the nominal diameter (refer to Appendix A) is 406.4mm.

If we assume a maximum gap of 0.3mm is acceptable, a typical phased array wedge for axial testing is approximately 25mm wide. This would mean that a wedge with a diameter of curvature between flat and around 240mm is acceptable.

On the long axis, an X3 wedge would be around 65mm long. The wedge DOC must be between about 370 and 460mm.

Phased array wedges must be made for the job; there is limited tolerance for using a single wedge on a variety of pipe diameters.

For small mono-element probes it may be possible to use a flat wedge (or to shape the wedge using emery paper or similar), but it is vital to then be able to confirm the probe angle using a suitable test-block, such as a measured piece of pipe with a surface mark. (Ensure this is detected at the correct distance.)

Angles

With a mono-element probe, the Sonatest Wave instrument can show the sound path within a curved pipe. This allows the correct stand-off distances to be determined so that the weld region is scanned fully. If the Wave or similar is not available refer to ISO16811 for guidance.

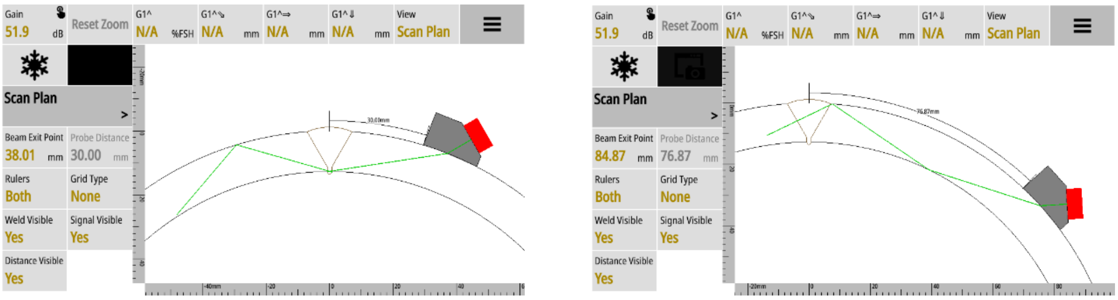

Figure 10 Using the WAVE software to determine scanning distance on seam welds

The Wave can also show when a particular inspection is not possible; for example, with a pipe that is thick in relation to its diameter, the sound beam with a standard 60 degree probe will never reach the inside of the weld and a different probe angle must be chosen.

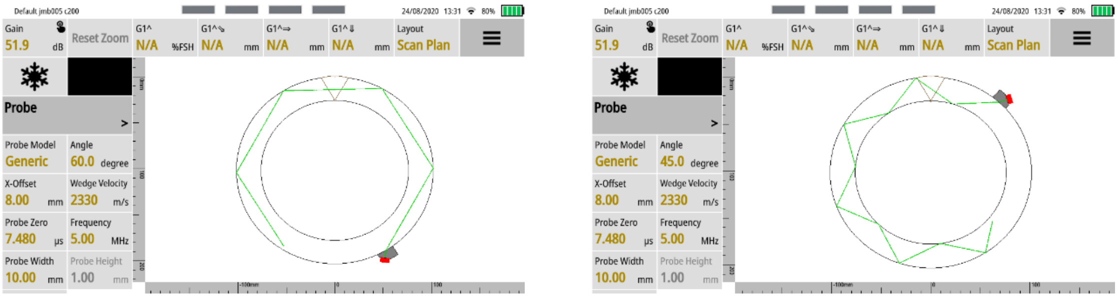

Figure 11 Using the WAVE software to confirm probe angle is suitable, the 60 degree probe does not reach the inner surface of the pipe

Once the sound path within the curved surface is understood, there is minimal difference inspecting girth and seam welds.

Phased array

Inspection of seam welds using phased array complicates the calculation significantly, because we must consider both the irregular shape of the wedge and the changes in angles on reflection.

This can only be done satisfactorily using an instrument or calculation program designed for the job.

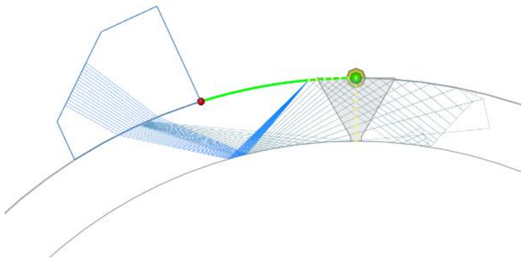

Figure 12 Phased Array beam calculation on a curved surface.

With the veo+, this requires that the curved surface correction software option is installed.

Again, once this is done the inspection is fairly similar to a girth weld of flat inspection.

Time of Flight Diffraction (TOFD)
With TOFD on flat plates, the lateral wave (first arriving, and thus shortest path) is along the surface of the plate. It will often be disrupted by the weld crown.

On curved surfaces the lateral wave will again follow the shortest path, but this is now slightly below the surface. Diffraction from points slightly above and slightly below the line will appear at the same position.

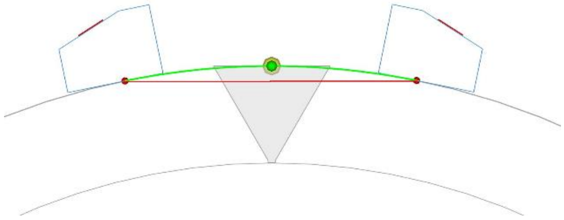

Figure 13 TOFD inspection on a curved surface

This does not mean that TOFD cannot be used across welds on curved surfaces, but considerably more experience and training is required to interpret the results.

Spiral welds

[Sonatest does not currently supply equipment recommended for online inspection of this type.]

Spiral welded tubes should always be inspected as part of the manufacturing process with an automated system, as they are inevitably impossible to manipulate easily for field inspection. Normal practice is to use a fixed inspection setup, with multiple (or phased array) probes located one or two spirals 'downstream' from the welding station. The pipe moves through the system and rotates, so the position of the fixed probes relative to the weld stays constant.

A row of probes is often used to inspect the body of the pipe at the same time.

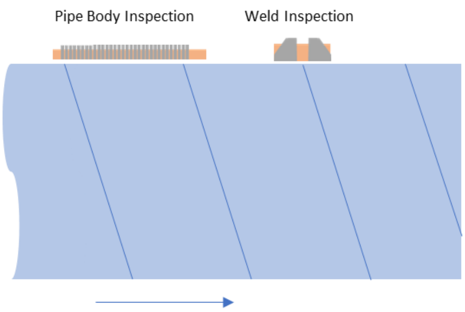

Figure 14 Arrangement for online inspection of Spiral Welded Tube.

If it is necessary to inspect some section of the weld manually, the diameter is normally large enough that the path across the weld line can be treated as nearly flat. However, the skip locations should be confirmed manually.

The author is unaware of any simple scanning systems suitable for manual inspection of spiral welds.

Practical aspects of inspection – scanners

As mentioned above, a key aspect of a successful weld inspection is the selection of a suitable scanner. Scanners perform two vital functions:

- Scanners carry the various probes in a suitable position relative to the weld and allow them to be held accurately while scanning along it. The number of probes is obviously a key aspect of a particular scanner design.
- Scanners also support a suitable encoder, allowing the exact position of the probe or probes to be recorded. This allows accurate measurements of the length and position of a defect to be made from the recorded data.

Broadly we can divide scanners into three categories:

Scanning systems for large diameter pipes

A typical example here would be the Phoenix Magman or the Jireh STIX scanner. These are typically the same as are used for flat welds and might carry a pair of phased array transducers, along with at least one pair of TOFD probes. Alternatively, several conventional probes may be installed.
The critical requirement is that the wheels and tool posts can be adjusted to fit around the pipe in the correct locations.

Figure 15 Jireh STIX scanner

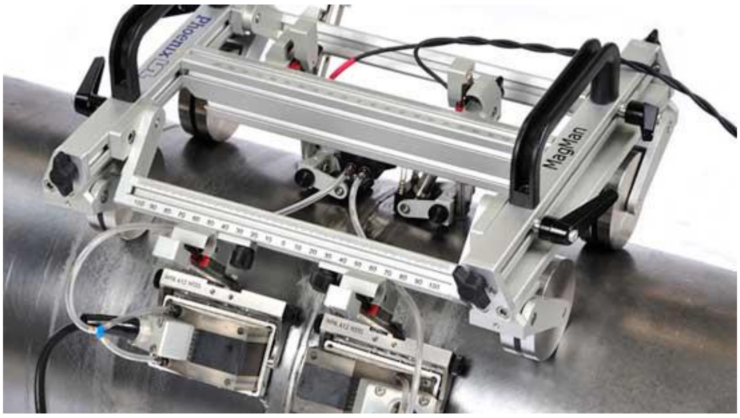

Figure 16 Phoenix Magman

Scanning systems for medium diameter pipes

On medium tubes (i.e a diameter of typically 100 to 300 millimetres), purpose-designed scanners with minimal width are normally required. A typical example would be the Jireh Rotix, or the Phoenix Multimag. These will typically hold a maximum of two pairs of probes.

Figure 17 Jireh ROTIX with Chain assembly

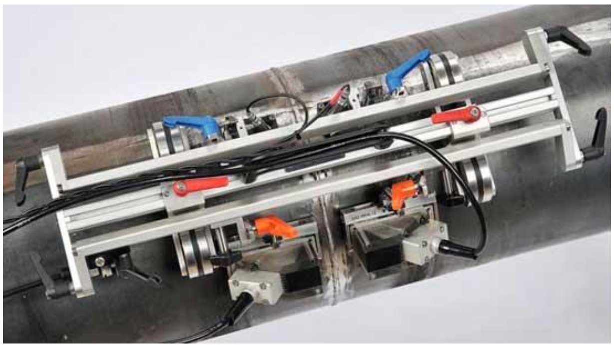

Figure 18 Phoenix Multimag

All these scanner configurations involve compromises, such as width vs. length. Some may be suitable for single sided access (e.g. when testing welds close to flanges or elbows), but this may make them slightly less stable than scanners with wheels on both sides of the weld.

Scanners may be held on to the pipe with magnetic wheels and/or a suitable chain arrangement. For non-magnetic materials, a chain or strap (as shown in Figure 17) is essential.

Scanners for small diameter pipes

For small diameter piping, custom miniature scanners are typically designed to be fixed onto the pipe using a quick release strap, so that they can then be rotated around it with the fingertips. These are typically fitted with one or two specially-designed phased array probes. In many cases the pipes that need to be inspected are close together, so a low-profile design is often important. Typical examples here are the Phoenix Bracelet scanner, the Jireh CIRC-IT, or the Waygate PALM scanner.

Small diameter piping also often has a relatively thin wall, so this may require a specialised technique for the ultrasonic setup. It may for example be difficult to use anything other than high angle scans, which will limit the depth resolution of an indication. Considerable experience can be required to interpret this situation successfully. The recently issued standard ISO 20601-2018 gives useful guidance here.

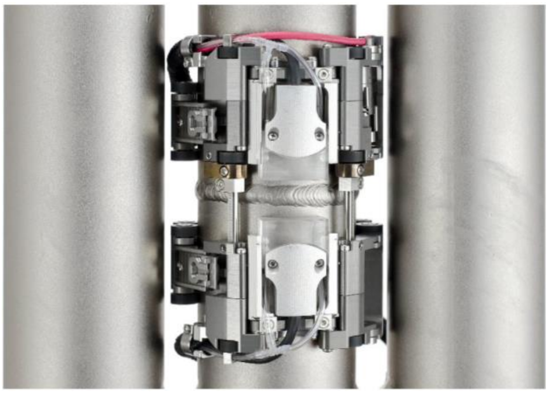

Figure 19 Jireh CIRC-IT

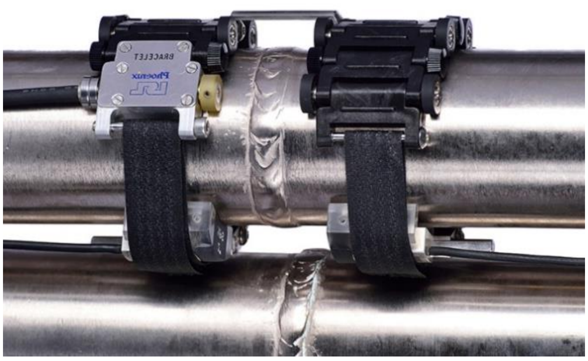

Figure 20 Phoenix Bracelet scanner

In general, all scanners fitted with suitable connectors are compatible with all phased array instruments.

Scanners for longitudinal welds

Normally these will be similar to those used for large diameter piping – and many scanner designs are adaptable for both applications – but it is essential that the wheels and probes can be adjusted to match the curvature in the circumferential direction.

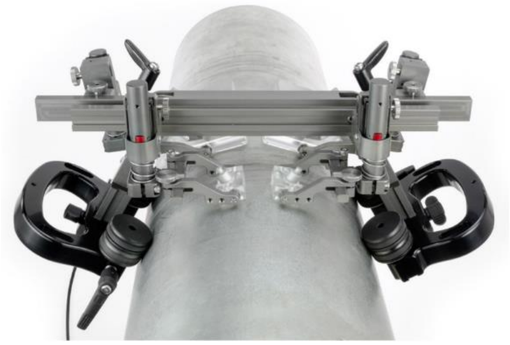

Figure 21 Jireh 'STIX' scanner with 'long seam weld' option

Appendix A Pipe sizes

Actual pipe diameters for twelve inch and below are not the same as the nominal pipe size.

Upper figure is thickness in mm, lower figure is weight in kgm^{-1}

Size NB	O.D. inches *mm*	Pipe Schedules															
		5s	5	10	10s	20	30	40s Std	40	60	80s E.H.	80	100	120	140	160	Dbl. E.H.
1/8	0.405 *10.29*		0.89 *0.21*	1.24 *0.28*	1.24 *0.28*			1.73 *0.36*	1.73 *0.36*		2.41 *0.47*	2.41 *0.47*					
1/4	0.54 *13.72*		1.24 *0.38*	1.65 *0.49*	1.65 *0.49*			2.24 *0.63*	2.24 *0.63*		3.02 *0.80*	3.02 *0.80*					
3/8	0.675 *17.15*		1.24 *0.49*	1.65 *0.63*	1.65 *0.63*			2.31 *0.84*	2.31 *0.84*		3.20 *1.09*	3.20 *1.09*					
1/2	0.84 *21.34*	1.65 *0.80*	1.65 *0.80*	2.11 *1.00*	2.11 *1.00*			2.77 *1.27*	2.77 *1.27*		3.73 *1.62*	3.73 *1.62*				4.78 *1.94*	7.47 *2.55*
3/4	1.05 *26.67*	1.65 *1.02*	1.65 *1.02*	2.11 *1.28*	2.11 *1.28*			2.87 *1.68*	2.87 *1.68*		3.91 *2.19*	3.91 *2.19*				5.56 *2.88*	7.82 *3.63*
1	1.315 *33.40*	1.65 *1.29*	1.65 *1.29*	2.77 *2.09*	2.77 *2.09*			3.38 *2.50*	3.38 *2.50*		4.55 *3.23*	4.55 *3.23*				6.35 *4.23*	9.09 *5.45*
1-1/4	1.66 *42.16*	1.65 *1.65*	1.65 *1.65*	2.77 *2.69*	2.77 *2.69*			3.56 *3.38*	3.56 *3.38*		4.85 *4.46*	4.85 *4.46*				6.35 *5.60*	9.70 *7.76*
1-1/2	1.9 *48.26*	1.65 *1.90*	1.65 *1.90*	2.77 *3.10*	2.77 *3.10*			3.68 *4.04*	3.68 *4.04*		5.08 *5.40*	5.08 *5.40*				7.14 *7.23*	10.16 *9.54*
2	2.375 *60.33*	1.65 *2.39*	1.65 *2.39*	2.77 *3.93*	2.77 *3.93*			3.91 *5.44*	3.91 *5.44*		5.54 *7.47*	5.54 *7.47*				8.74 *11.1*	11.07 *13.4*
2-1/2	2.875 *73.03*	2.11 *3.68*	2.11 *3.68*	3.05 *5.25*	3.05 *5.25*			5.16 *8.62*	5.16 *8.62*		7.01 *11.4*	7.01 *11.4*				9.53 *14.9*	14.02 *20.4*
3	3.5 *88.90*	2.11 *4.51*	2.11 *4.51*	3.05 *6.45*	3.05 *6.45*			5.49 *11.3*	5.49 *11.3*		7.62 *15.3*	7.62 *15.3*				11.13 *21.3*	15.24 *27.7*
3-1/2	4 *101.6*	2.11 *5.17*	2.11 *5.17*	3.05 *7.40*	3.05 *7.40*			5.74 *13.6*	5.74 *13.6*		8.08 *18.6*	8.08 *18.6*					16.15 *34.0*
4	4.5 *114.3*	2.11 *5.83*	2.11 *5.83*	3.05 *8.35*	3.05 *8.35*			6.02 *16.1*	6.02 *16.1*	7.14 *18.8*	8.56 *22.3*	8.56 *22.3*		11.13 *28.3*		13.49 *33.5*	17.12 *41.0*
4-1/2	5 *127.0*							6.27 *18.6*			9.02 *26.2*						18.03 *48.4*
5	5.563 *141.3*	2.77 *9.45*	2.77 *9.45*	3.40 *11.6*	3.40 *11.6*			6.55 *21.8*	6.55 *21.8*		9.53 *30.9*	9.53 *30.9*		12.70 *40.2*		15.88 *49.1*	19.05 *57.4*
6	6.625 *168.3*	2.77 *11.3*	2.77 *11.3*	3.40 *13.8*	3.40 *13.8*			7.11 *28.2*	7.11 *28.2*		10.97 *42.5*	10.97 *42.5*		14.27 *54.2*		18.26 *67.4*	21.95 *79.1*
7	7.625 *193.7*							7.65 *35.1*			12.70 *56.6*						22.23 *93.9*
8	8.625 *219.1*	2.77 *14.8*	2.77 *14.8*	3.76 *19.9*	3.76 *19.9*	6.35 *33.3*	7.04 *36.8*	8.18 *42.5*	8.18 *42.5*	10.31 *53.0*	12.70 *64.6*	12.70 *64.6*	15.09 *75.7*	18.26 *90.7*	20.62 *100.8*	23.01 *111.2*	22.23 *107.8*
9	9.625 *244.5*							8.69 *50.4*			12.70 *72.5*						
10	10.75 *273.1*	3.40 *22.6*	3.40 *22.6*	4.19 *27.8*	4.19 *27.8*	6.35 *41.7*	7.80 *51.0*	9.27 *60.2*	9.27 *60.2*	12.70 *81.5*	12.70 *81.5*	15.09 *95.7*	18.26 *114.5*	21.44 *132.7*	25.40 *154.9*	28.58 *172.1*	25.40 *155.0*
11	11.75 *298.5*							9.53 *67.8*			12.70 *89.4*						
12	12.75 *323.9*	3.96 *31.4*	4.19 *33.0*	4.57 *36.0*	4.57 *36.0*	6.35 *49.7*	8.38 *65.1*	9.53 *73.8*	10.31 *79.7*	14.27 *108.9*	12.70 *97.4*	17.48 *131.7*	21.44 *159.5*	25.40 *186.8*	28.58 *207.9*	33.32 *238.7*	
14	14 *355.6*	3.96 *34.3*		6.35 *54.6*	4.78 *41.3*	7.92 *68.0*	9.53 *81.2*	9.53 *81.2*	11.13 *94.3*	15.09 *126.4*	12.70 *107.3*	19.05 *157.9*	23.83 *194.5*	27.79 *224.3*	31.75 *253.3*	35.71 *281.4*	
16	16 *406.4*	4.19 *41.5*		6.35 *62.6*	4.78 *47.2*	7.92 *77.9*	9.53 *93.1*	9.53 *93.1*	12.70 *123.2*	16.66 *160.0*	12.70 *123.2*	21.44 *203.1*	26.19 *245.3*	30.94 *286.2*	36.50 *332.6*	40.49 *364.8*	
18	18 *457.2*	4.19 *46.8*		6.35 *70.5*	4.78 *53.2*	7.92 *87.8*	11.13 *122.1*	9.53 *105.1*	14.27 *156.0*	19.05 *205.7*	12.70 *139.1*	23.83 *254.2*	29.36 *309.5*	34.93 *363.3*	39.67 *408.1*	45.24 *459.1*	
20	20 *508.0*	4.78 *59.2*		6.35 *78.5*	5.54 *68.9*	9.53 *117.0*	12.70 *154.9*	9.53 *117.0*	15.09 *182.9*	20.62 *247.6*	12.70 *154.9*	26.19 *310.9*	32.54 *381.1*	38.10 *441.1*	44.45 *507.6*	50.01 *564.0*	
24	24 *609.6*	5.54 *82.4*		6.35 *94.4*	6.35 *94.4*	9.53 *140.8*	14.27 *209.5*	9.53 *140.8*	17.48 *254.8*	24.61 *354.3*	12.70 *186.8*	30.96 *441.1*	38.89 *546.8*	46.02 *639.0*	52.37 *718.9*	59.54 *806.4*	
26	26 *660.4*				7.92 *127.4*	12.70 *202.6*		9.53 *152.7*			12.70 *202.6*						
28	28 *711.2*				7.92 *137.3*	12.70 *218.5*	15.88 *271.9*	9.53 *164.7*									
30	30 *762.0*	0.25 *79.4*		7.92 *146.8*	7.92 *147.2*	12.70 *234.4*	15.88 *291.8*	9.53 *176.6*			12.70 *234.4*						
32	32 *812.8*				7.92 *157.1*	12.70 *250.3*	15.88 *311.7*	9.53 *188.5*	17.48 *342.4*		12.70 *250.3*						
34	34 *863.6*				7.92 *167.0*	12.70 *266.2*	15.88 *331.5*	9.53 *200.4*	17.48 *364.3*								
36	36 *914.4*				7.92 *177.0*		15.88 *351.4*	9.53 *212.3*	19.05 *420.2*		12.70 *282.1*						

References

ESWedgegap software can be downloaded from
https://eclipsescientific.com/Software/Download/SetupESWedgeGap.exe

