Header Ligament Crack Detection and Sizing
UT Techniques

by Jimmy Ellis 718-757-9464 utgeek@earthlink.net

associated with

Rick Pfannenstiel, PfiNDE, LLC 860-830-4990 www.PfiNDE.com

Header Ligament Crack Detection and Sizing
UT Techniques

The following describes some ultrasonic testing techniques for the detection and sizing of ligament cracks in headers. These techniques can also be used for other applications in flat plate or cylindrical sections.

Contents

by Jimmy Ellis 718-757-9464 utgeek@earthlink.net

associated with

Rick Pfannenstiel, PfiNDE, LLC 860-830-4990 www.PfiNDE.com

Header Ligament Crack Detection and Sizing

Objective

The objective of this series of examinations is to detect ligament cracks and then determine the depth of the ligament cracking between penetrations in headers.

Scope

The types of headers these methods are intended for are power boiler headers with thick pipe walls and numerous closely spaced penetrations such as found in superheater headers.

Cracks in headers are most often detected by remote visual inspection from inside the header. Sometimes there are 'hand holes' in the header ends, and sometimes pipe penetrations are cut off to make an access for a fibercam or other remote visual device. Even with a confirmed visual detection, the depth sizing can be difficult.

Some headers with extra heavy wall thickness are difficult to inspect with conventional shear wave techniques. Due to the angles usually used, and the thickness and curvature of the header, shear waves often won't reach the ID (inside diameter) of the header. Other drawbacks of shear waves are the difficulty in detecting crack tip signals and the high response to corner reflectors

The methods described here are also applicable to other product forms with flat plate or cylindrical type shapes.

Two crack orientations are considered; axial and radial.

Techniques

Radial Cracks

Radial cracks are circumferentially oriented in the header pipe and go from one penetration to the adjacent penetration in the circumferential direction. Three UT techniques are described:

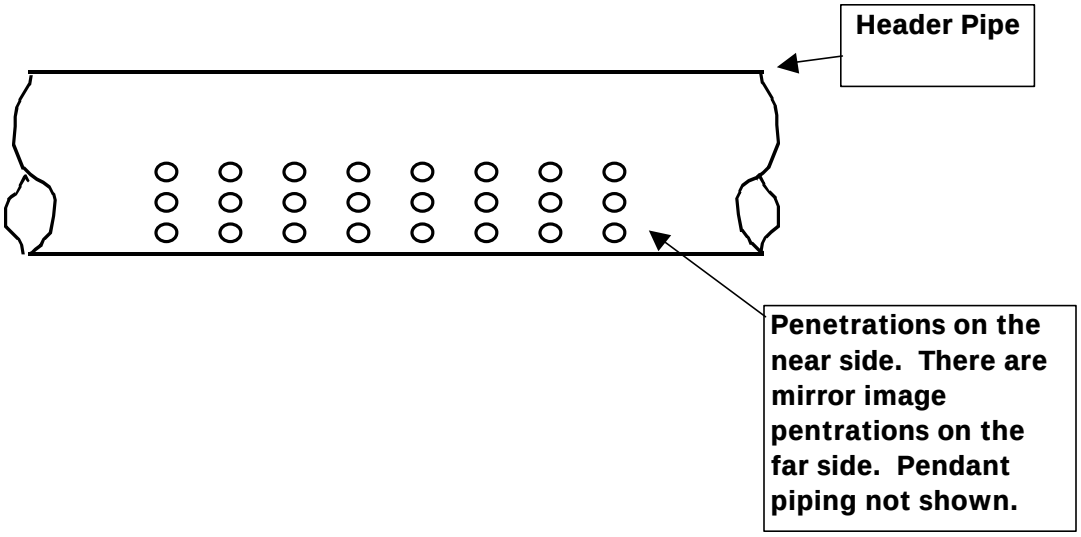
- FAST-UT
- Pitch-Catch
- Manual TOFD (for flat plate type geometries)

Axial Cracks

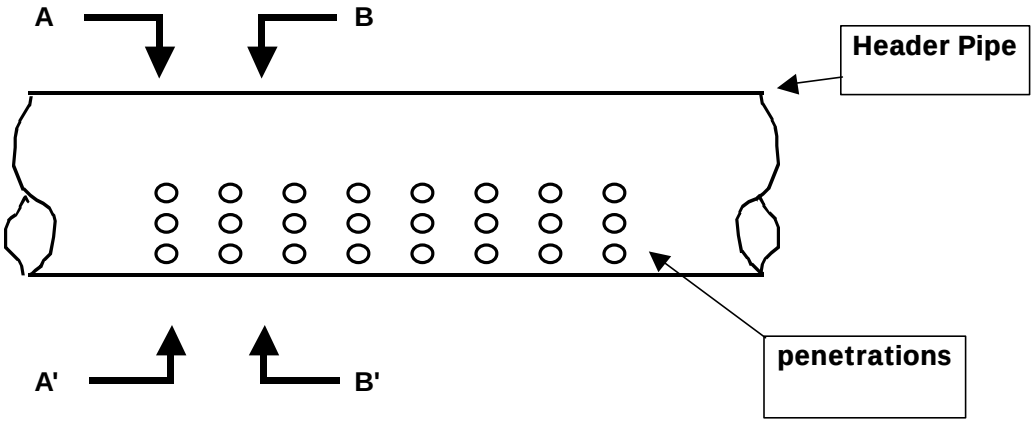
Axial cracks are parallel to the axis of the header pipe and go from one penetration to the adjacent penetration in the header pipe axial direction. Two UT techniques are described:

- Through-Transmission
- Manual TOFD (circumferentially oriented in cylindrical sections)

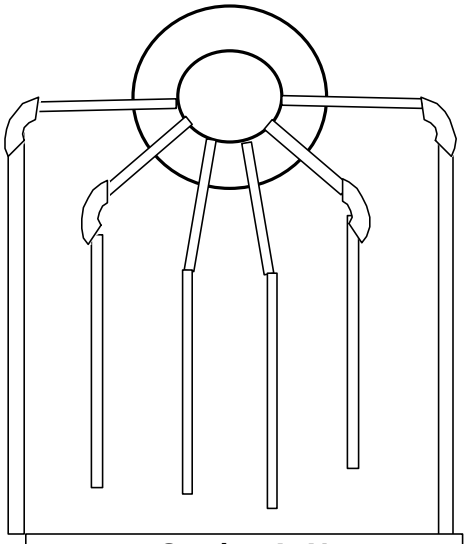
Illustrations of radial and axial cracks in headers follow.



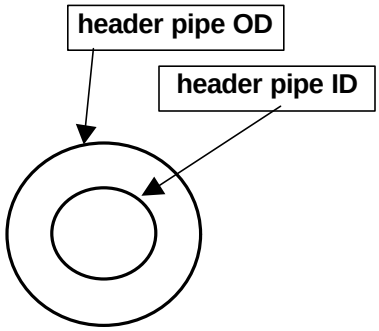
Side view of Header



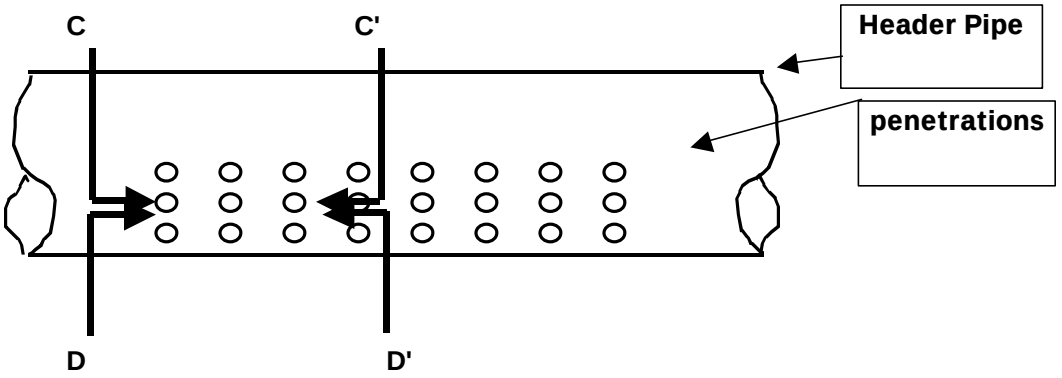
Side view of Header



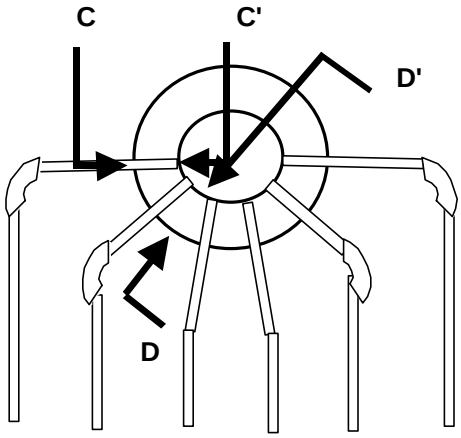
Section A-A'
Radial Section,
Sectioned through penetrations

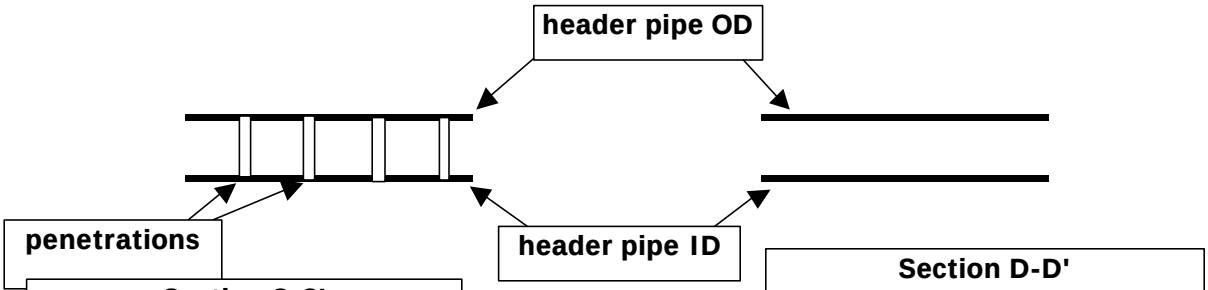


Section B-B'
Radial Section,
Sectioned between penetrations



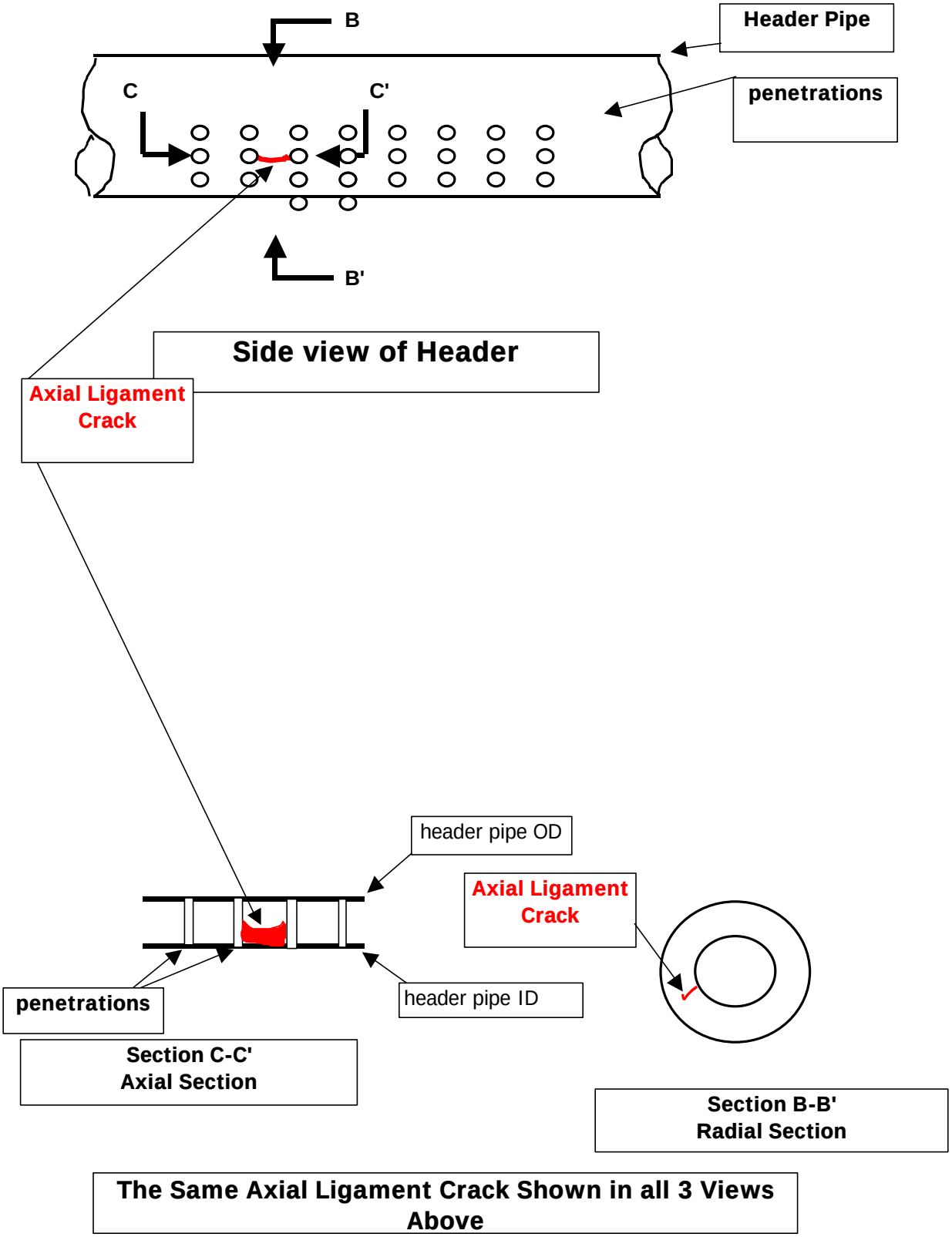
Side view of Header



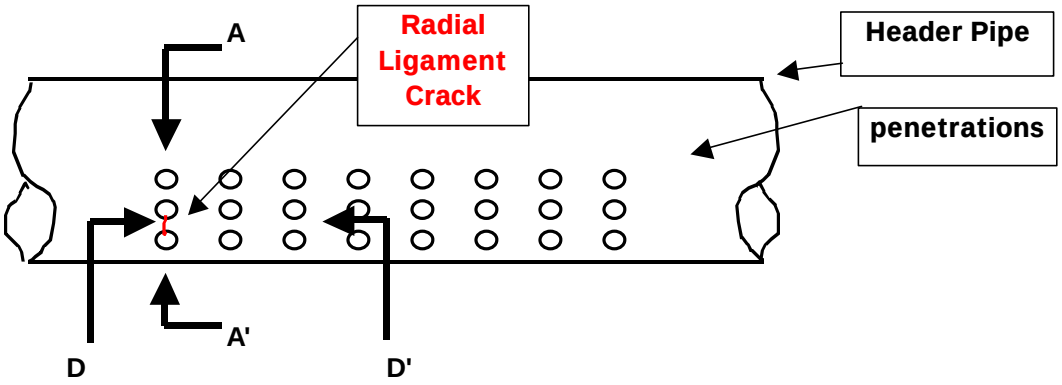


**Section C-C'
Axial Section
Sectioned through penetrations
(only the near side header pipe wall and penetrations are shown)**

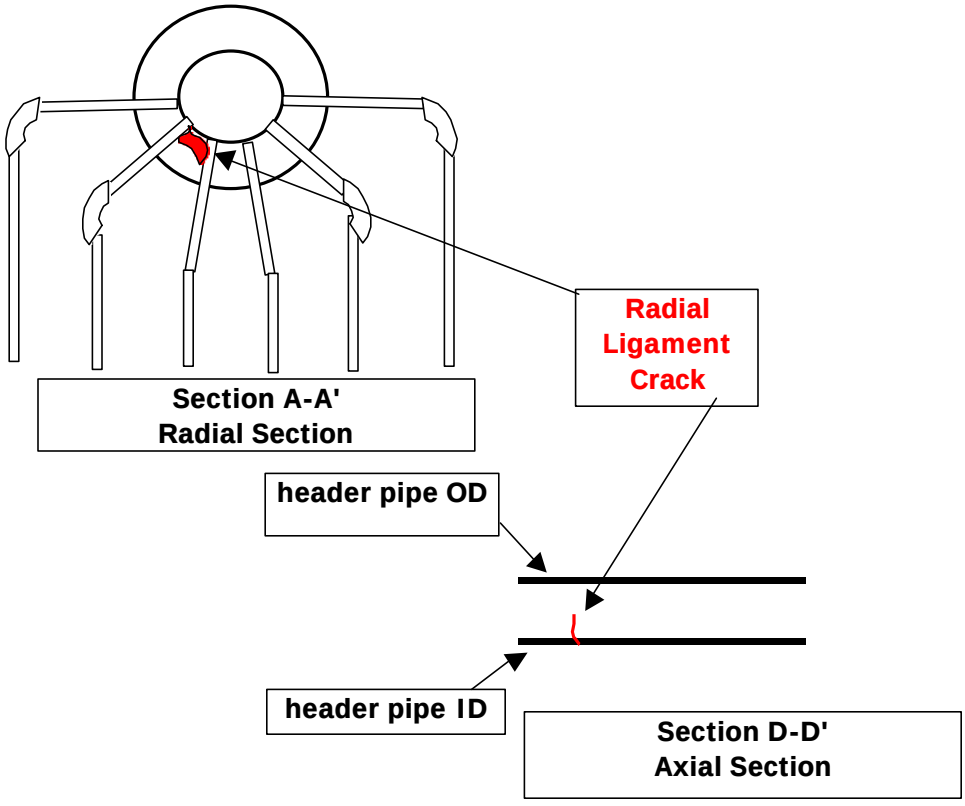
**Section D-D'
Axial Section
Sectioned between penetrations
(only the near side header pipe wall is shown)**



The Same Axial Ligament Crack Shown in all 3 Views Above



Side view of Header



The Same Radial Ligament Crack Shown in all 3 Views Above

Radial Ligament Crack Detection and Sizing

Three methods are considered for the detection and sizing of radial header ligament cracking:

1____FAST-UT
2____Pitch-Catch
3____Manual TOFD

FAST-UT

FAST-UT is a proprietary multipurpose ultrasonic inspection technique. FAST-UT predominantly uses high angle L-waves, but low angle shear waves, and ID and OD creeper modes of sound propagation are also present and useful.

A detailed description of the technique is beyond the scope of this presentation. More details can be found through www.PfiNDE.com .

For most in-service ultrasonic inspection, FAST-UT can perform most ultrasonic inspections with the highest reliability of detection, the lowest rate of false calls, and in the hands of experienced examiners, detection and sizing can often be performed together. Most power plant piping can have reliable in-service ultrasonic inspection with FAST-UT alone. FAST-UT has been thoroughly tested and proved through the EPRI (Electric Power Research Institute) PDI (Performance Demonstration Initiative) Program.

The geometry of radial cracks is similar to flat plate, as shown in the previous section D-D'. Due to the similarity in geometry of radial cracks to cracks in flat plate, it is possible that many radial cracks may be detected and sized with FAST-UT alone.

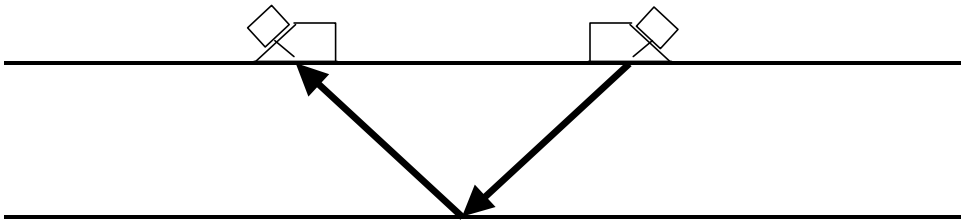
Pitch-Catch

The following sketches show the set-up for measuring the depth of cracking for ID connected radial cracks. These pitch-catch transducers are shear wave transducers set up in an axial orientation on the header. The geometry of radial cracks is similar to flat plate, as shown in the previous section D-D'.

pitch-catch set-up

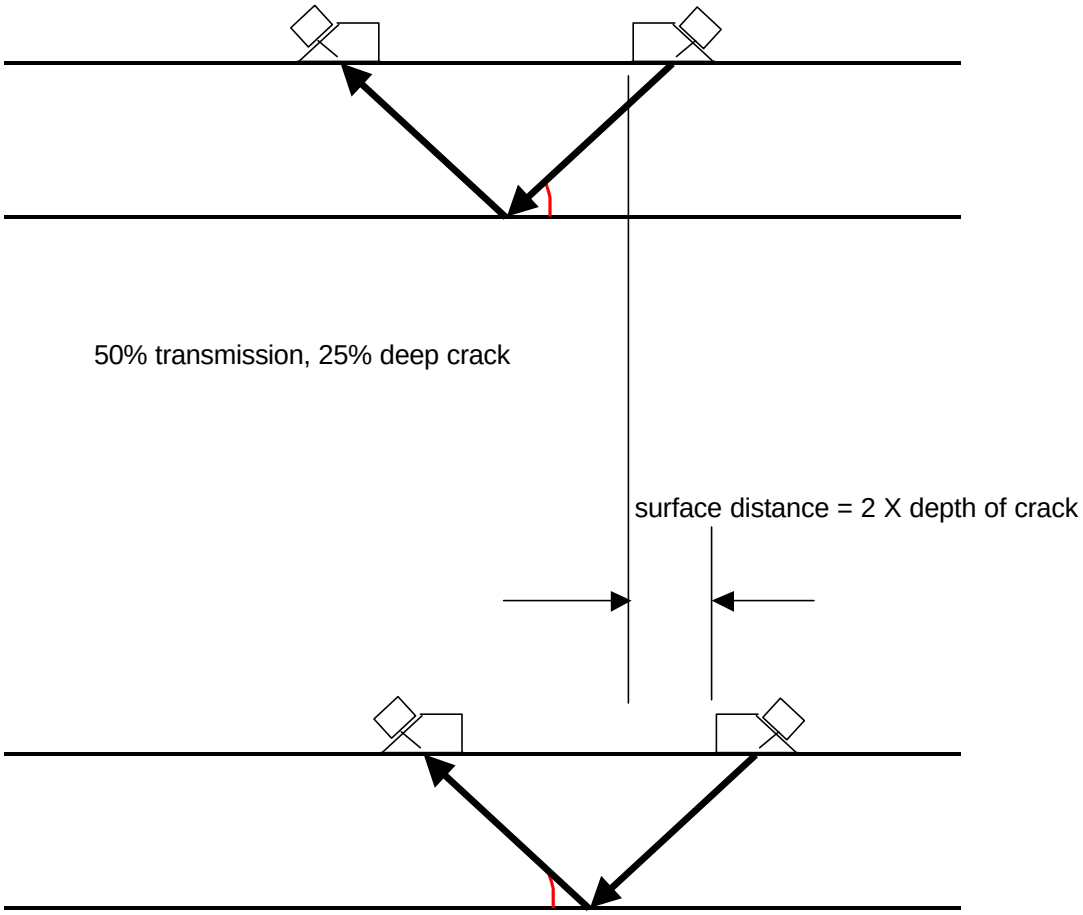
45 degree shear wave transducers

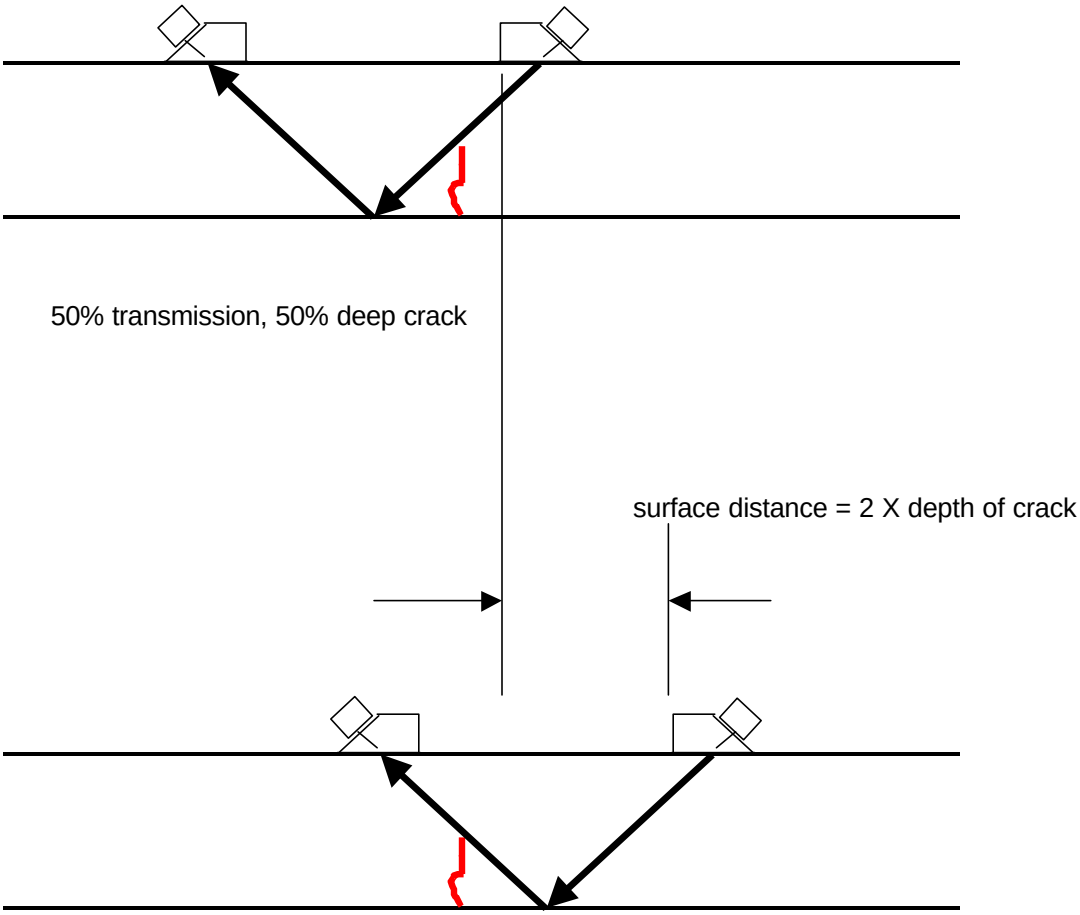
surface distance = depth



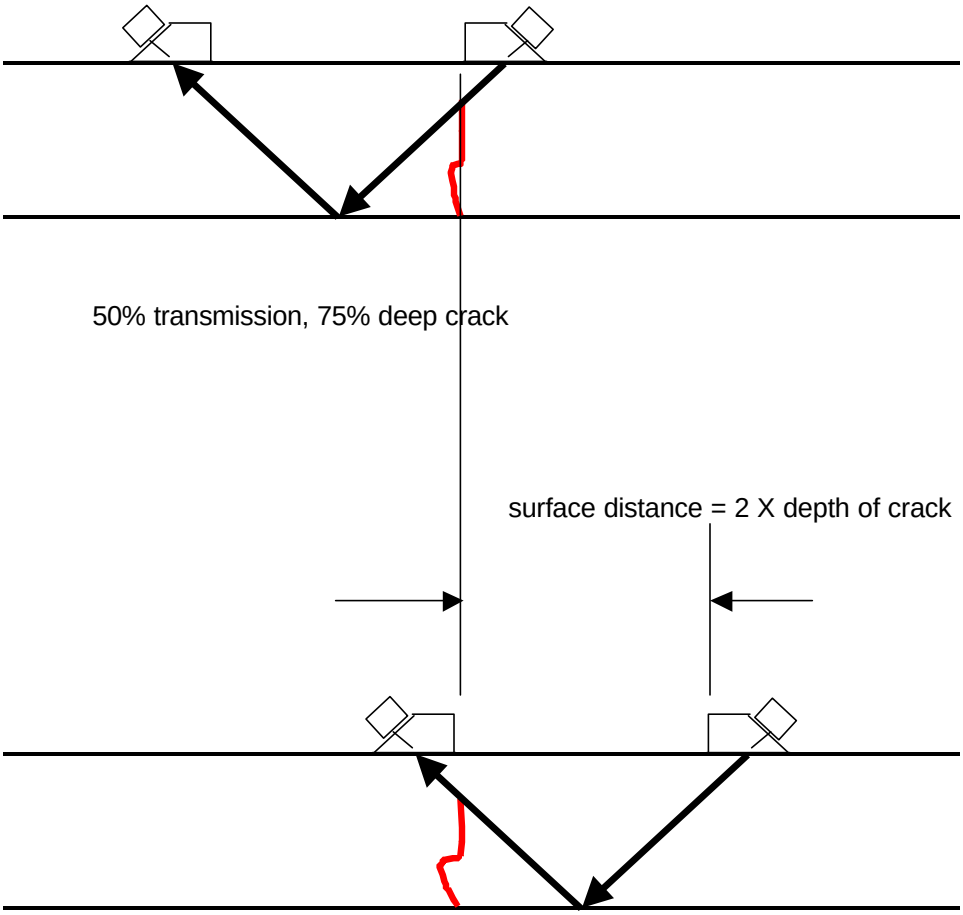
100% transmision, no interfering cracks

similar to geometry of Section D-D'

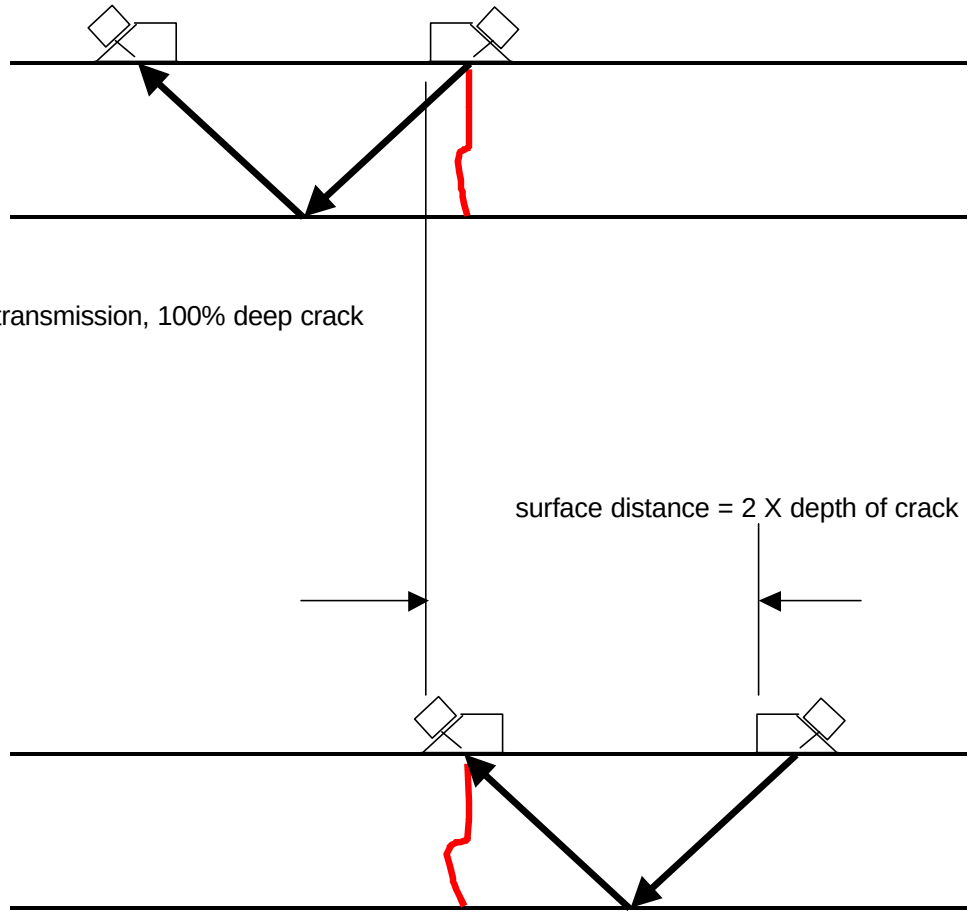

50% transmission, 25% deep crack
surface distance = 2 X depth of crack
50% transmission, 25% deep crack



50% transmission, 50% deep crack



50% transmission, 75% deep crack



50% transmission, 100% deep crack

Manual TOFD

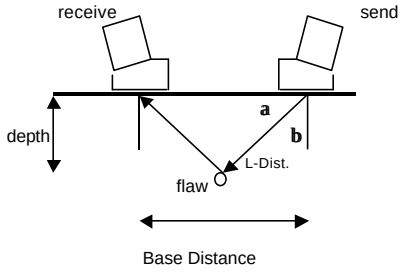
Manual TOFD of radial cracks uses axially oriented transducers in pitch-catch pairs. The transducer pair can scan axially, or circumferentially.

TOFD (**T**ime **o**f **F**light Tip **D**iffraction Testing) is almost universally performed as an automated ultrasonic test where the scans are electronically recorded for later display in an image. Special scanners, detectors, hardware and software is required. The manual technique shown here is somewhat unique in that it allows TOFD to be performed in real time at a client's convenience and schedule, with only a normal ultrasonic flaw detector.

This manual TOFD technique compliments the FAST-UT technique. The FAST-UT technique predominantly uses a high angle L-wave at 70 degrees. This results in a long surface distance, about 2.75" of surface distance for each inch of depth. The manual TOFD technique compliments the FAST-UT because it needs only short surface distances. For example a flaw 6 inches deep can be sized with only 1.5" of surface distance on each side of the flaw centerline.

Radial cracks in headers have a geometry similar to flat plate as shown in the previous section D-D'. The following sketches and Microsoft Excel spreadsheet show the geometric relations which make up the manual TOFD set-up in flat plate. Then additional spreadsheet derived tables are shown for a series of increasing base distances in round numbers for examples. The Excel spreadsheet can calculate a precise table for any chosen base distance.

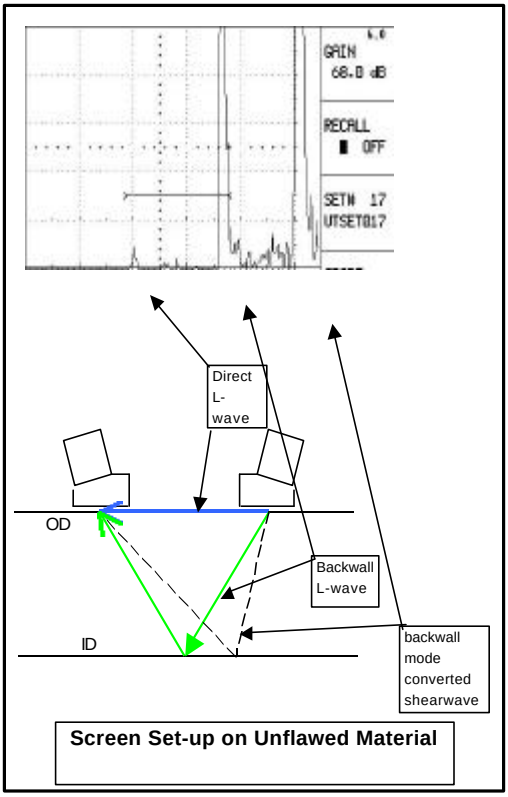
For use with a machine that has only a 'dual' setting and no 'pitch-catch such as USN52L.
Set the L-wave X-ducers to the needed base distance, then input this distance in this spreadsheet.
Set up the screen with the Direct L-wave at 1, the Backwall L-wave at 5 and the Backwall Mode-converted shearwave at 10.
Set the Backwall L-wave echo in the gate and use 'Zero' to calibrate. (L-Dist. is read from S-path displayed)
Measure flaws in the gate to measure L-Distances and refer to the table for depth determination.
For sensitivity setting, set SDH nearest maximum depth of interest at 50%FSH.



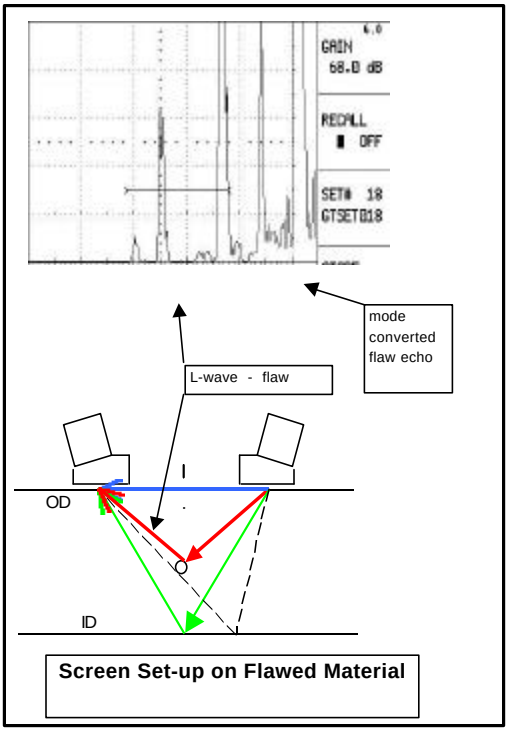
Input Base Distance:

1.0 inches

depth (or thickness)	L-Dist.	angle a	X-ducer angle b	beam spreads at 5MHz 30° 17°-43'	45° 32°-58°	60° 47°-73°
0.1	0.51	11.31	78.69			
0.2	0.54	21.80	68.20			
0.3	0.58	30.96	59.04			
0.4	0.64	38.66	51.34			
0.5	0.71	45.00	45.00			
0.6	0.78	50.19	39.81			
0.7	0.86	54.46	35.54			
0.8	0.94	57.99	32.01			
0.9	1.03	60.95	29.05			
1	1.12	63.43	26.57			
1.1	1.21	65.56	24.44			
1.2	1.30	67.38	22.62			
1.3	1.39	68.96	21.04			
1.4	1.49	70.35	19.65			
1.5	1.58	71.57	18.43			
1.6	1.68	72.65	17.35			
1.7	1.77	73.61	16.39			
1.8	1.87	74.48	15.52			
1.9	1.96	75.26	14.74			
2	2.06	75.96	14.04			
2.1	2.16	76.61	13.39			
2.2	2.26	77.20	12.80			
2.3	2.35	77.74	12.26			
2.4	2.45	78.23	11.77			
2.5	2.55	78.69	11.31			
2.6	2.65	79.11	10.89			
2.7	2.75	79.51	10.49			
2.8	2.84	79.88	10.12			
2.9	2.94	80.22	9.78			
3	3.04	80.54	9.46			
3.1	3.14	80.84	9.16			
3.2	3.24	81.12	8.88			
3.3	3.34	81.38	8.62			
3.4	3.44	81.63	8.37			
3.5	3.54	81.87	8.13			



Screen Set-up on Unflawed Material



Screen Set-up on Flawed Material

Input Base Distance:
0.25 inches

depth (or thickness)	L-Dist.	angle	X-ducer angle		30° 17°-43°	45° 32°-58°	60° 47°-73°
0.1	0.16	38.66	51.34				
0.2	0.24	57.99	32.01				
0.3	0.33	67.38	22.62				
0.4	0.42	72.65	17.35				
0.5	0.52	75.96	14.04				
0.6	0.61	78.23	11.77				
0.7	0.71	79.88	10.12				
0.8	0.81	81.12	8.88				
0.9	0.91	82.09	7.91				
1	1.01	82.87	7.13				
1.1	1.11	83.52	6.48				
1.2	1.21	84.05	5.95				
1.3	1.31	84.51	5.49				
1.4	1.41	84.90	5.10				
1.5	1.51	85.24	4.76				
1.6	1.60	85.53	4.47				
1.7	1.70	85.79	4.21				
1.8	1.80	86.03	3.97				
1.9	1.90	86.24	3.76				
2	2.00	86.42	3.58				
2.1	2.10	86.59	3.41				
2.2	2.20	86.75	3.25				
2.3	2.30	86.89	3.11				
2.4	2.40	87.02	2.98				
2.5	2.50	87.14	2.86				
2.6	2.60	87.25	2.75				
2.7	2.70	87.35	2.65				
2.8	2.80	87.44	2.56				
2.9	2.90	87.53	2.47				
3	3.00	87.61	2.39				
3.1	3.10	87.69	2.31				
3.2	3.20	87.76	2.24				
3.3	3.30	87.83	2.17				
3.4	3.40	87.89	2.11				
3.5	3.50	87.95	2.05				

Input Base Distance:
0.50 inches

depth (or thickness)	L-Dist.	angle	X-ducer angle		30° 17°-43°	45° 32°-58°	60° 47°-73°
0.1	0.27	21.80	68.20				
0.2	0.32	38.66	51.34				
0.3	0.39	50.19	39.81				
0.4	0.47	57.99	32.01				
0.5	0.56	63.43	26.57				
0.6	0.65	67.38	22.62				
0.7	0.74	70.35	19.65				
0.8	0.84	72.65	17.35				
0.9	0.93	74.48	15.52				
1	1.03	75.96	14.04				
1.1	1.13	77.20	12.80				
1.2	1.23	78.23	11.77				
1.3	1.32	79.11	10.89				
1.4	1.42	79.88	10.12				
1.5	1.52	80.54	9.46				
1.6	1.62	81.12	8.88				
1.7	1.72	81.63	8.37				
1.8	1.82	82.09	7.91				
1.9	1.92	82.50	7.50				
2	2.02	82.87	7.13				
2.1	2.11	83.21	6.79				
2.2	2.21	83.52	6.48				
2.3	2.31	83.80	6.20				
2.4	2.41	84.05	5.95				
2.5	2.51	84.29	5.71				
2.6	2.61	84.51	5.49				
2.7	2.71	84.71	5.29				
2.8	2.81	84.90	5.10				
2.9	2.91	85.07	4.93				
3	3.01	85.24	4.76				
3.1	3.11	85.39	4.61				
3.2	3.21	85.53	4.47				
3.3	3.31	85.67	4.33				
3.4	3.41	85.79	4.21				
3.5	3.51	85.91	4.09				

Input Base Distance:
0.75 inches

depth (or thickness)	L-Dist.	angle	X-ducer angle		30° 17°-43°	45° 32°-58°	60° 47°-73°
0.1	0.39	14.93	75.07				
0.2	0.43	28.07	61.93				
0.3	0.48	38.66	51.34				
0.4	0.55	46.85	43.15				
0.5	0.63	53.13	36.87				
0.6	0.71	57.99	32.01				
0.7	0.79	61.82	28.18				
0.8	0.88	64.89	25.11				
0.9	0.98	67.38	22.62				
1	1.07	69.44	20.56				
1.1	1.16	71.18	18.82				
1.2	1.26	72.65	17.35				
1.3	1.35	73.91	16.09				
1.4	1.45	75.00	15.00				
1.5	1.55	75.96	14.04				
1.6	1.64	76.81	13.19				
1.7	1.74	77.56	12.44				
1.8	1.84	78.23	11.77				
1.9	1.94	78.84	11.16				
2	2.03	79.38	10.62				
2.1	2.13	79.88	10.12				
2.2	2.23	80.33	9.67				
2.3	2.33	80.74	9.26				
2.4	2.43	81.12	8.88				
2.5	2.53	81.47	8.53				
2.6	2.63	81.79	8.21				
2.7	2.73	82.09	7.91				
2.8	2.83	82.37	7.63				
2.9	2.92	82.63	7.37				
3	3.02	82.87	7.13				
3.1	3.12	83.10	6.90				
3.2	3.22	83.32	6.68				
3.3	3.32	83.52	6.48				
3.4	3.42	83.71	6.29				
3.5	3.52	83.88	6.12				

Input Base Distance:
1.00 inches

depth (or thickness)	L-Dist.	angle	X-ducer angle		30° 17°-43°	45° 32°-58°	60° 47°-73°
0.1	0.51	11.31	78.69				
0.2	0.54	21.80	68.20				
0.3	0.58	30.96	59.04				
0.4	0.64	38.66	51.34				
0.5	0.71	45.00	45.00				
0.6	0.78	50.19	39.81				
0.7	0.86	54.46	35.54				
0.8	0.94	57.99	32.01				
0.9	1.03	60.95	29.05				
1	1.12	63.43	26.57				
1.1	1.21	65.56	24.44				
1.2	1.30	67.38	22.62				
1.3	1.39	68.96	21.04				
1.4	1.49	70.35	19.65				
1.5	1.58	71.57	18.43				
1.6	1.68	72.65	17.35				
1.7	1.77	73.61	16.39				
1.8	1.87	74.48	15.52				
1.9	1.96	75.26	14.74				
2	2.06	75.96	14.04				
2.1	2.16	76.61	13.39				
2.2	2.26	77.20	12.80				
2.3	2.35	77.74	12.26				
2.4	2.45	78.23	11.77				
2.5	2.55	78.69	11.31				
2.6	2.65	79.11	10.89				
2.7	2.75	79.51	10.49				
2.8	2.84	79.88	10.12				
2.9	2.94	80.22	9.78				
3	3.04	80.54	9.46				
3.1	3.14	80.84	9.16				
3.2	3.24	81.12	8.88				
3.3	3.34	81.38	8.62				
3.4	3.44	81.63	8.37				
3.5	3.54	81.87	8.13				

Input Base Distance:
1.50 inches

depth (or thickness)	L-Dist.	angle	X-ducer angle		30° 17°-43°	45° 32°-58°	60° 47°-73°
0.1	0.76	7.59	82.41				
0.2	0.78	14.93	75.07				
0.3	0.81	21.80	68.20				
0.4	0.85	28.07	61.93				
0.5	0.90	33.69	56.31				
0.6	0.96	38.66	51.34				
0.7	1.03	43.03	46.97				
0.8	1.10	46.85	43.15				
0.9	1.17	50.19	39.81				
1	1.25	53.13	36.87				
1.1	1.33	55.71	34.29				
1.2	1.42	57.99	32.01				
1.3	1.50	60.02	29.98				
1.4	1.59	61.82	28.18				
1.5	1.68	63.43	26.57				
1.6	1.77	64.89	25.11				
1.7	1.86	66.19	23.81				
1.8	1.95	67.38	22.62				
1.9	2.04	68.46	21.54				
2	2.14	69.44	20.56				
2.1	2.23	70.35	19.65				
2.2	2.32	71.18	18.82				
2.3	2.42	71.94	18.06				
2.4	2.51	72.65	17.35				
2.5	2.61	73.30	16.70				
2.6	2.71	73.91	16.09				
2.7	2.80	74.48	15.52				
2.8	2.90	75.00	15.00				
2.9	3.00	75.50	14.50				
3	3.09	75.96	14.04				
3.1	3.19	76.40	13.60				
3.2	3.29	76.81	13.19				
3.3	3.38	77.20	12.80				
3.4	3.48	77.56	12.44				
3.5	3.58	77.91	12.09				

Input Base Distance:
2.0 inches

depth (or thickness)	L-Dist.	angle	X-ducer angle		30° 17°-43°	45° 32°-58°	60° 47°-73°
0.1	1.00	5.71	84.29				
0.2	1.02	11.31	78.69				
0.3	1.04	16.70	73.30				
0.4	1.08	21.80	68.20				
0.5	1.12	26.57	63.43				
0.6	1.17	30.96	59.04				
0.7	1.22	34.99	55.01				
0.8	1.28	38.66	51.34				
0.9	1.35	41.99	48.01				
1	1.41	45.00	45.00				
1.1	1.49	47.73	42.27				
1.2	1.56	50.19	39.81				
1.3	1.64	52.43	37.57				
1.4	1.72	54.46	35.54				
1.5	1.80	56.31	33.69				
1.6	1.89	57.99	32.01				
1.7	1.97	59.53	30.47				
1.8	2.06	60.95	29.05				
1.9	2.15	62.24	27.76				
2	2.24	63.43	26.57				
2.1	2.33	64.54	25.46				
2.2	2.42	65.56	24.44				
2.3	2.51	66.50	23.50				
2.4	2.60	67.38	22.62				
2.5	2.69	68.20	21.80				
2.6	2.79	68.96	21.04				
2.7	2.88	69.68	20.32				
2.8	2.97	70.35	19.65				
2.9	3.07	70.97	19.03				
3	3.16	71.57	18.43				
3.1	3.26	72.12	17.88				
3.2	3.35	72.65	17.35				
3.3	3.45	73.14	16.86				
3.4	3.54	73.61	16.39				
3.5	3.64	74.05	15.95				

Input Base Distance:
2.5 inches

depth (or thickness)	L-Dist.	angle	X-ducer angle		30° 17°-43°	45° 32°-58°	60° 47°-73°
0.1	1.25	4.57	85.43				
0.2	1.27	9.09	80.91				
0.3	1.29	13.50	76.50				
0.4	1.31	17.74	72.26				
0.5	1.35	21.80	68.20				
0.6	1.39	25.64	64.36				
0.7	1.43	29.25	60.75				
0.8	1.48	32.62	57.38				
0.9	1.54	35.75	54.25				
1	1.60	38.66	51.34				
1.1	1.67	41.35	48.65				
1.2	1.73	43.83	46.17				
1.3	1.80	46.12	43.88				
1.4	1.88	48.24	41.76				
1.5	1.95	50.19	39.81				
1.6	2.03	52.00	38.00				
1.7	2.11	53.67	36.33				
1.8	2.19	55.22	34.78				
1.9	2.27	56.66	33.34				
2	2.36	57.99	32.01				
2.1	2.44	59.24	30.76				
2.2	2.53	60.40	29.60				
2.3	2.62	61.48	28.52				
2.4	2.71	62.49	27.51				
2.5	2.80	63.43	26.57				
2.6	2.88	64.32	25.68				
2.7	2.98	65.16	24.84				
2.8	3.07	65.94	24.06				
2.9	3.16	66.68	23.32				
3	3.25	67.38	22.62				
3.1	3.34	68.04	21.96				
3.2	3.44	68.66	21.34				
3.3	3.53	69.25	20.75				
3.4	3.62	69.81	20.19				
3.5	3.72	70.35	19.65				
3.6	3.81	70.85	19.15				
3.7	3.91	71.33	18.67				
3.8	4.00	71.79	18.21				
3.9	4.10	72.23	17.77				
4	4.19	72.65	17.35				
4.1	4.29	73.04	16.96				
4.2	4.38	73.43	16.57				
4.3	4.48	73.79	16.21				
4.4	4.57	74.14	15.86				
4.5	4.67	74.48	15.52				
4.6	4.77	74.80	15.20				
4.7	4.86	75.11	14.89				
4.8	4.96	75.40	14.60				
4.9	5.06	75.69	14.31				
5	5.15	75.96	14.04				

Input Base Distance:
3.0 inches

depth (or thickness)	L-Dist.	angle	X-ducer angle		30° 17°-43°	45° 32°-58°	60° 47°-73°
0.1	1.50	3.81	86.19				
0.2	1.51	7.59	82.41				
0.3	1.53	11.31	78.69				
0.4	1.55	14.93	75.07				
0.5	1.58	18.43	71.57				
0.6	1.62	21.80	68.20				
0.7	1.66	25.02	64.98				
0.8	1.70	28.07	61.93				
0.9	1.75	30.96	59.04				
1	1.80	33.69	56.31				
1.1	1.86	36.25	53.75				
1.2	1.92	38.66	51.34				
1.3	1.98	40.91	49.09				
1.4	2.05	43.03	46.97				
1.5	2.12	45.00	45.00				
1.6	2.19	46.85	43.15				
1.7	2.27	48.58	41.42				
1.8	2.34	50.19	39.81				
1.9	2.42	51.71	38.29				
2	2.50	53.13	36.87				
2.1	2.58	54.46	35.54				
2.2	2.66	55.71	34.29				
2.3	2.75	56.89	33.11				
2.4	2.83	57.99	32.01				
2.5	2.92	59.04	30.96				
2.6	3.00	60.02	29.98				
2.7	3.09	60.95	29.05				
2.8	3.18	61.82	28.18				
2.9	3.26	62.65	27.35				
3	3.35	63.43	26.57				
3.1	3.44	64.18	25.82				
3.2	3.53	64.89	25.11				
3.3	3.62	65.56	24.44				
3.4	3.72	66.19	23.81				
3.5	3.81	66.80	23.20				
3.6	3.90	67.38	22.62				
3.7	3.99	67.93	22.07				
3.8	4.09	68.46	21.54				
3.9	4.18	68.96	21.04				
4	4.27	69.44	20.56				
4.1	4.37	69.90	20.10				
4.2	4.46	70.35	19.65				
4.3	4.55	70.77	19.23				
4.4	4.65	71.18	18.82				
4.5	4.74	71.57	18.43				
4.6	4.84	71.94	18.06				
4.7	4.93	72.30	17.70				
4.8	5.03	72.65	17.35				
4.9	5.12	72.98	17.02				
5	5.22	73.30	16.70				

Input Base Distance:
3.5 inches

depth (or thickness)	L-Dist.	angle	X-ducer angle		30° 17°-43°	45° 32°-58°	60° 47°-73°
0.1	1.75	3.27	86.73				
0.2	1.76	6.52	83.48				
0.3	1.78	9.73	80.27				
0.4	1.80	12.88	77.12				
0.5	1.82	15.95	74.05				
0.6	1.85	18.92	71.08				
0.7	1.88	21.80	68.20				
0.8	1.92	24.57	65.43				
0.9	1.97	27.22	62.78				
1	2.02	29.74	60.26				
1.1	2.07	32.15	57.85				
1.2	2.12	34.44	55.56				
1.3	2.18	36.61	53.39				
1.4	2.24	38.66	51.34				
1.5	2.30	40.60	49.40				
1.6	2.37	42.44	47.56				
1.7	2.44	44.17	45.83				
1.8	2.51	45.81	44.19				
1.9	2.58	47.35	42.65				
2	2.66	48.81	41.19				
2.1	2.73	50.19	39.81				
2.2	2.81	51.50	38.50				
2.3	2.89	52.73	37.27				
2.4	2.97	53.90	36.10				
2.5	3.05	55.01	34.99				
2.6	3.13	56.06	33.94				
2.7	3.22	57.05	32.95				
2.8	3.30	57.99	32.01				
2.9	3.39	58.89	31.11				
3	3.47	59.74	30.26				
3.1	3.56	60.55	29.45				
3.2	3.65	61.33	28.67				
3.3	3.74	62.06	27.94				
3.4	3.82	62.76	27.24				
3.5	3.91	63.43	26.57				
3.6	4.00	64.08	25.92				
3.7	4.09	64.69	25.31				
3.8	4.18	65.27	24.73				
3.9	4.27	65.83	24.17				
4	4.37	66.37	23.63				
4.1	4.46	66.89	23.11				
4.2	4.55	67.38	22.62				
4.3	4.64	67.85	22.15				
4.4	4.74	68.31	21.69				
4.5	4.83	68.75	21.25				
4.6	4.92	69.17	20.83				
4.7	5.02	69.58	20.42				
4.8	5.11	69.97	20.03				
4.9	5.20	70.35	19.65				
5	5.30	70.71	19.29				

Input Base Distance:
4.0 inches

depth (or thickness)	L-Dist.	angle	X-ducer angle		30° 17°-43°	45° 32°-58°	60° 47°-73°
0.1	2.00	2.86	87.14				
0.2	2.01	5.71	84.29				
0.3	2.02	8.53	81.47				
0.4	2.04	11.31	78.69				
0.5	2.06	14.04	75.96				
0.6	2.09	16.70	73.30				
0.7	2.12	19.29	70.71				
0.8	2.15	21.80	68.20				
0.9	2.19	24.23	65.77				
1	2.24	26.57	63.43				
1.1	2.28	28.81	61.19				
1.2	2.33	30.96	59.04				
1.3	2.39	33.02	56.98				
1.4	2.44	34.99	55.01				
1.5	2.50	36.87	53.13				
1.6	2.56	38.66	51.34				
1.7	2.62	40.36	49.64				
1.8	2.69	41.99	48.01				
1.9	2.76	43.53	46.47				
2	2.83	45.00	45.00				
2.1	2.90	46.40	43.60				
2.2	2.97	47.73	42.27				
2.3	3.05	48.99	41.01				
2.4	3.12	50.19	39.81				
2.5	3.20	51.34	38.66				
2.6	3.28	52.43	37.57				
2.7	3.36	53.47	36.53				
2.8	3.44	54.46	35.54				
2.9	3.52	55.41	34.59				
3	3.61	56.31	33.69				
3.1	3.69	57.17	32.83				
3.2	3.77	57.99	32.01				
3.3	3.86	58.78	31.22				
3.4	3.94	59.53	30.47				
3.5	4.03	60.26	29.74				
3.6	4.12	60.95	29.05				
3.7	4.21	61.61	28.39				
3.8	4.29	62.24	27.76				
3.9	4.38	62.85	27.15				
4	4.47	63.43	26.57				
4.1	4.56	64.00	26.00				
4.2	4.65	64.54	25.46				
4.3	4.74	65.06	24.94				
4.4	4.83	65.56	24.44				
4.5	4.92	66.04	23.96				
4.6	5.02	66.50	23.50				
4.7	5.11	66.95	23.05				
4.8	5.20	67.38	22.62				
4.9	5.29	67.80	22.20				
5	5.39	68.20	21.80				

Input Base Distance:
4.5 inches

depth (or thickness)	L-Dist.	angle	X-ducer angle		30° 17°-43°	45° 32°-58°	60° 47°-73°
0.1	2.25	2.54	87.46				
0.2	2.26	5.08	84.92				
0.3	2.27	7.59	82.41				
0.4	2.29	10.08	79.92				
0.5	2.30	12.53	77.47				
0.6	2.33	14.93	75.07				
0.7	2.36	17.28	72.72				
0.8	2.39	19.57	70.43				
0.9	2.42	21.80	68.20				
1	2.46	23.96	66.04				
1.1	2.50	26.05	63.95				
1.2	2.55	28.07	61.93				
1.3	2.60	30.02	59.98				
1.4	2.65	31.89	58.11				
1.5	2.70	33.69	56.31				
1.6	2.76	35.42	54.58				
1.7	2.82	37.07	52.93				
1.8	2.88	38.66	51.34				
1.9	2.94	40.18	49.82				
2	3.01	41.63	48.37				
2.1	3.08	43.03	46.97				
2.2	3.15	44.36	45.64				
2.3	3.22	45.63	44.37				
2.4	3.29	46.85	43.15				
2.5	3.36	48.01	41.99				
2.6	3.44	49.13	40.87				
2.7	3.51	50.19	39.81				
2.8	3.59	51.22	38.78				
2.9	3.67	52.19	37.81				
3	3.75	53.13	36.87				
3.1	3.83	54.03	35.97				
3.2	3.91	54.89	35.11				
3.3	3.99	55.71	34.29				
3.4	4.08	56.50	33.50				
3.5	4.16	57.26	32.74				
3.6	4.25	57.99	32.01				
3.7	4.33	58.70	31.30				
3.8	4.42	59.37	30.63				
3.9	4.50	60.02	29.98				
4	4.59	60.64	29.36				
4.1	4.68	61.24	28.76				
4.2	4.76	61.82	28.18				
4.3	4.85	62.38	27.62				
4.4	4.94	62.92	27.08				
4.5	5.03	63.43	26.57				
4.6	5.12	63.94	26.06				
4.7	5.21	64.42	25.58				
4.8	5.30	64.89	25.11				
4.9	5.39	65.34	24.66				
5	5.48	65.77	24.23				

Input Base Distance:
5.0 inches

depth (or thickness)	L-Dist.	angle	X-ducer angle		30° 17°-43°	45° 32°-58°	60° 47°-73°
0.1	2.50	2.29	87.71				
0.2	2.51	4.57	85.43				
0.3	2.52	6.84	83.16				
0.4	2.53	9.09	80.91				
0.5	2.55	11.31	78.69				
0.6	2.57	13.50	76.50				
0.7	2.60	15.64	74.36				
0.8	2.62	17.74	72.26				
0.9	2.66	19.80	70.20				
1	2.69	21.80	68.20				
1.1	2.73	23.75	66.25				
1.2	2.77	25.64	64.36				
1.3	2.82	27.47	62.53				
1.4	2.87	29.25	60.75				
1.5	2.92	30.96	59.04				
1.6	2.97	32.62	57.38				
1.7	3.02	34.22	55.78				
1.8	3.08	35.75	54.25				
1.9	3.14	37.23	52.77				
2	3.20	38.66	51.34				
2.1	3.26	40.03	49.97				
2.2	3.33	41.35	48.65				
2.3	3.40	42.61	47.39				
2.4	3.47	43.83	46.17				
2.5	3.54	45.00	45.00				
2.6	3.61	46.12	43.88				
2.7	3.68	47.20	42.80				
2.8	3.75	48.24	41.76				
2.9	3.83	49.24	40.76				
3	3.91	50.19	39.81				
3.1	3.98	51.12	38.88				
3.2	4.06	52.00	38.00				
3.3	4.14	52.85	37.15				
3.4	4.22	53.67	36.33				
3.5	4.30	54.46	35.54				
3.6	4.38	55.22	34.78				
3.7	4.47	55.95	34.05				
3.8	4.55	56.66	33.34				
3.9	4.63	57.34	32.66				
4	4.72	57.99	32.01				
4.1	4.80	58.63	31.37				
4.2	4.89	59.24	30.76				
4.3	4.97	59.83	30.17				
4.4	5.06	60.40	29.60				
4.5	5.15	60.95	29.05				
4.6	5.24	61.48	28.52				
4.7	5.32	61.99	28.01				
4.8	5.41	62.49	27.51				
4.9	5.50	62.97	27.03				
5	5.59	63.43	26.57				

Input Base Distance:
5.5 inches

depth (or thickness)	L-Dist.	angle	X-ducer angle		30° 17°-43°	45° 32°-58°	60° 47°-73°
0.1	2.75	2.08	87.92				
0.2	2.76	4.16	85.84				
0.3	2.77	6.23	83.77				
0.4	2.78	8.28	81.72				
0.5	2.80	10.30	79.70				
0.6	2.81	12.31	77.69				
0.7	2.84	14.28	75.72				
0.8	2.86	16.22	73.78				
0.9	2.89	18.12	71.88				
1	2.93	19.98	70.02				
1.1	2.96	21.80	68.20				
1.2	3.00	23.57	66.43				
1.3	3.04	25.30	64.70				
1.4	3.09	26.98	63.02				
1.5	3.13	28.61	61.39				
1.6	3.18	30.19	59.81				
1.7	3.23	31.72	58.28				
1.8	3.29	33.21	56.79				
1.9	3.34	34.64	55.36				
2	3.40	36.03	53.97				
2.1	3.46	37.37	52.63				
2.2	3.52	38.66	51.34				
2.3	3.59	39.91	50.09				
2.4	3.65	41.11	48.89				
2.5	3.72	42.27	47.73				
2.6	3.78	43.39	46.61				
2.7	3.85	44.47	45.53				
2.8	3.92	45.52	44.48				
2.9	4.00	46.52	43.48				
3	4.07	47.49	42.51				
3.1	4.14	48.42	41.58				
3.2	4.22	49.33	40.67				
3.3	4.30	50.19	39.81				
3.4	4.37	51.03	38.97				
3.5	4.45	51.84	38.16				
3.6	4.53	52.62	37.38				
3.7	4.61	53.38	36.62				
3.8	4.69	54.11	35.89				
3.9	4.77	54.81	35.19				
4	4.85	55.49	34.51				
4.1	4.94	56.15	33.85				
4.2	5.02	56.78	33.22				
4.3	5.10	57.40	32.60				
4.4	5.19	57.99	32.01				
4.5	5.27	58.57	31.43				
4.6	5.36	59.13	30.87				
4.7	5.45	59.67	30.33				
4.8	5.53	60.19	29.81				
4.9	5.62	60.70	29.30				
5	5.71	61.19	28.81				

Input Base Distance:
6.0 inches

depth (or thickness)	L-Dist.	angle	X-ducer angle		30° 17°-43°	45° 32°-58°	60° 47°-73°
0.1	3.00	1.91	88.09				
0.2	3.01	3.81	86.19				
0.3	3.01	5.71	84.29				
0.4	3.03	7.59	82.41				
0.5	3.04	9.46	80.54				
0.6	3.06	11.31	78.69				
0.7	3.08	13.13	76.87				
0.8	3.10	14.93	75.07				
0.9	3.13	16.70	73.30				
1	3.16	18.43	71.57				
1.1	3.20	20.14	69.86				
1.2	3.23	21.80	68.20				
1.3	3.27	23.43	66.57				
1.4	3.31	25.02	64.98				
1.5	3.35	26.57	63.43				
1.6	3.40	28.07	61.93				
1.7	3.45	29.54	60.46				
1.8	3.50	30.96	59.04				
1.9	3.55	32.35	57.65				
2	3.61	33.69	56.31				
2.1	3.66	34.99	55.01				
2.2	3.72	36.25	53.75				
2.3	3.78	37.48	52.52				
2.4	3.84	38.66	51.34				
2.5	3.91	39.81	50.19				
2.6	3.97	40.91	49.09				
2.7	4.04	41.99	48.01				
2.8	4.10	43.03	46.97				
2.9	4.17	44.03	45.97				
3	4.24	45.00	45.00				
3.1	4.31	45.94	44.06				
3.2	4.39	46.85	43.15				
3.3	4.46	47.73	42.27				
3.4	4.53	48.58	41.42				
3.5	4.61	49.40	40.60				
3.6	4.69	50.19	39.81				
3.7	4.76	50.96	39.04				
3.8	4.84	51.71	38.29				
3.9	4.92	52.43	37.57				
4	5.00	53.13	36.87				
4.1	5.08	53.81	36.19				
4.2	5.16	54.46	35.54				
4.3	5.24	55.10	34.90				
4.4	5.33	55.71	34.29				
4.5	5.41	56.31	33.69				
4.6	5.49	56.89	33.11				
4.7	5.58	57.45	32.55				
4.8	5.66	57.99	32.01				
4.9	5.75	58.52	31.48				
5	5.83	59.04	30.96				

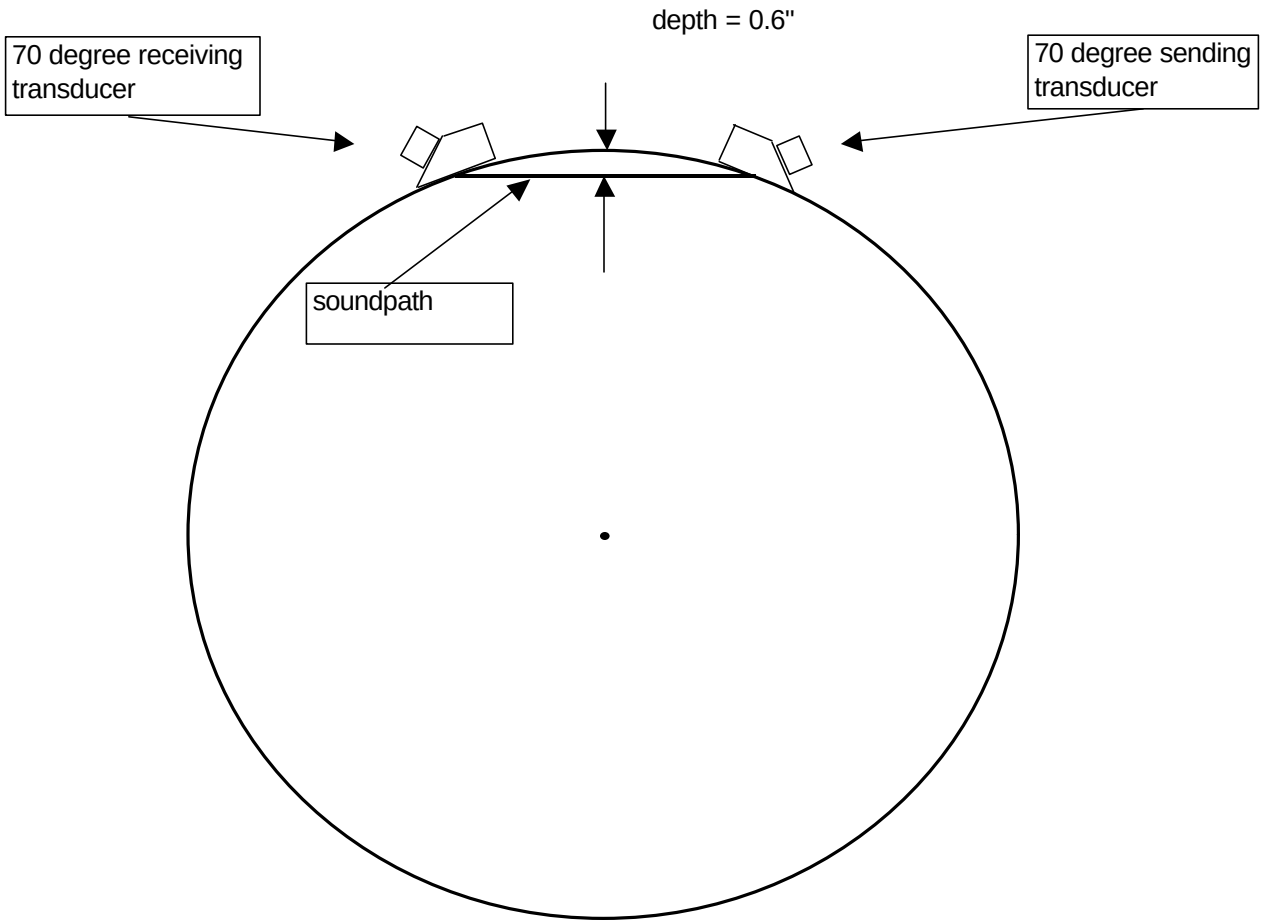
Axial Ligament Crack Detection & Sizing

Two techniques for detection and sizing of axial header ligament cracking:

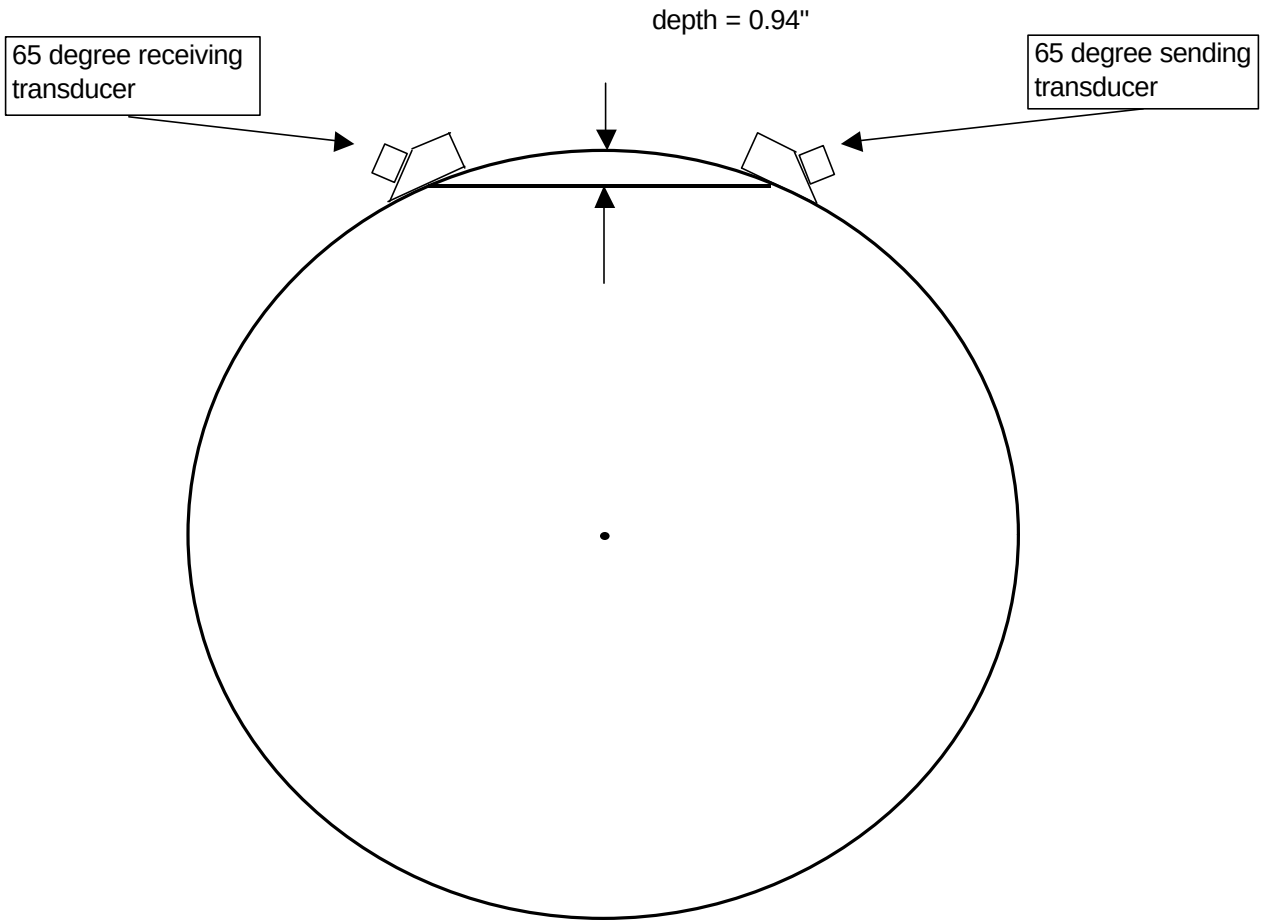
1_____Through-Transmission
2_____Manual TOFD

Through-Transmission

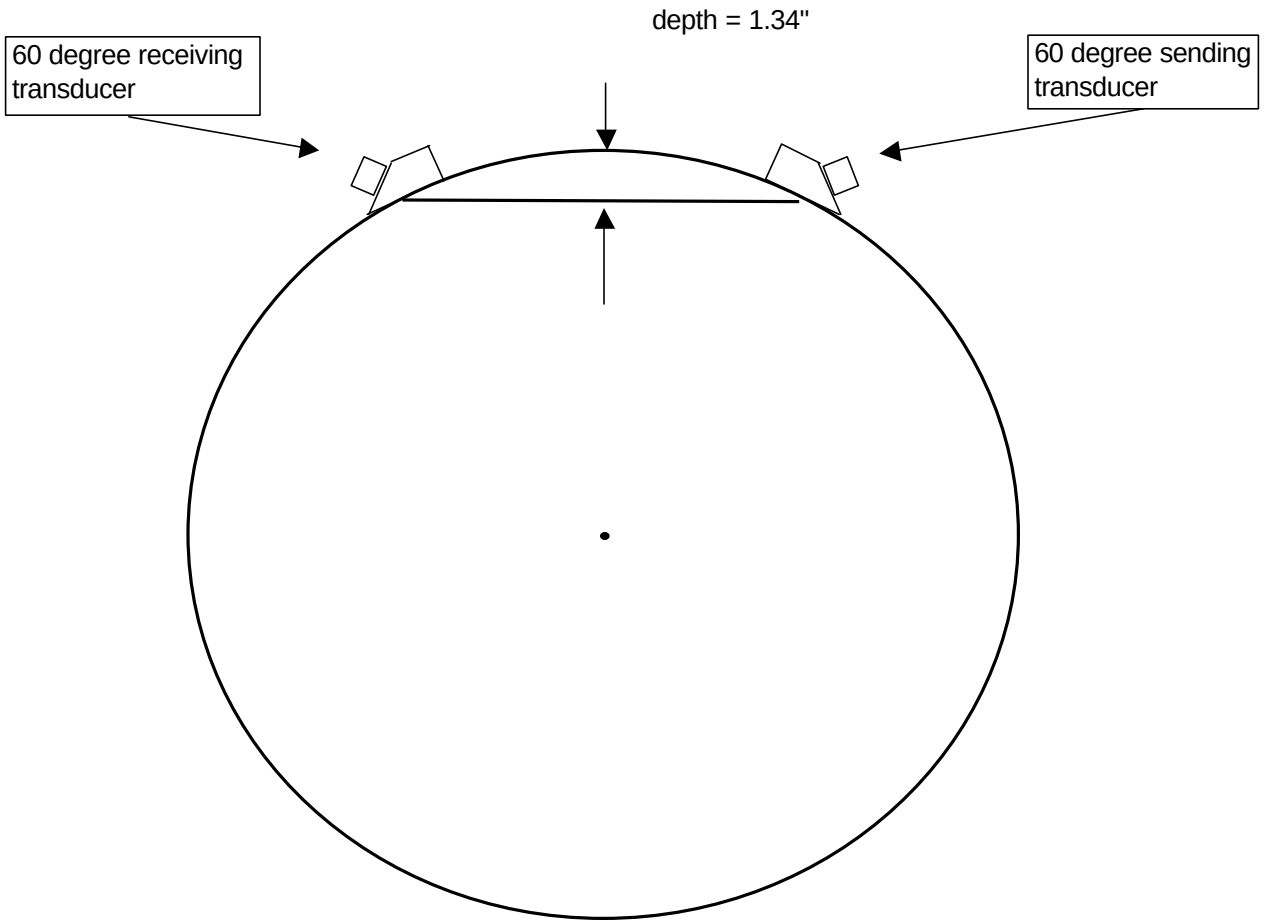
The orientations of axial ligament cracks as shown in the previous section B-B' are used as the basis of the 'Through-Transmission' ultrasonic set up. The following sketches show a series of transducer positions for 'Through-Transmission' set ups for a series of progressively smaller transducer sound angles for a header. Only the OD of the header is shown. As an example, a header with an outside diameter of 20" is shown.



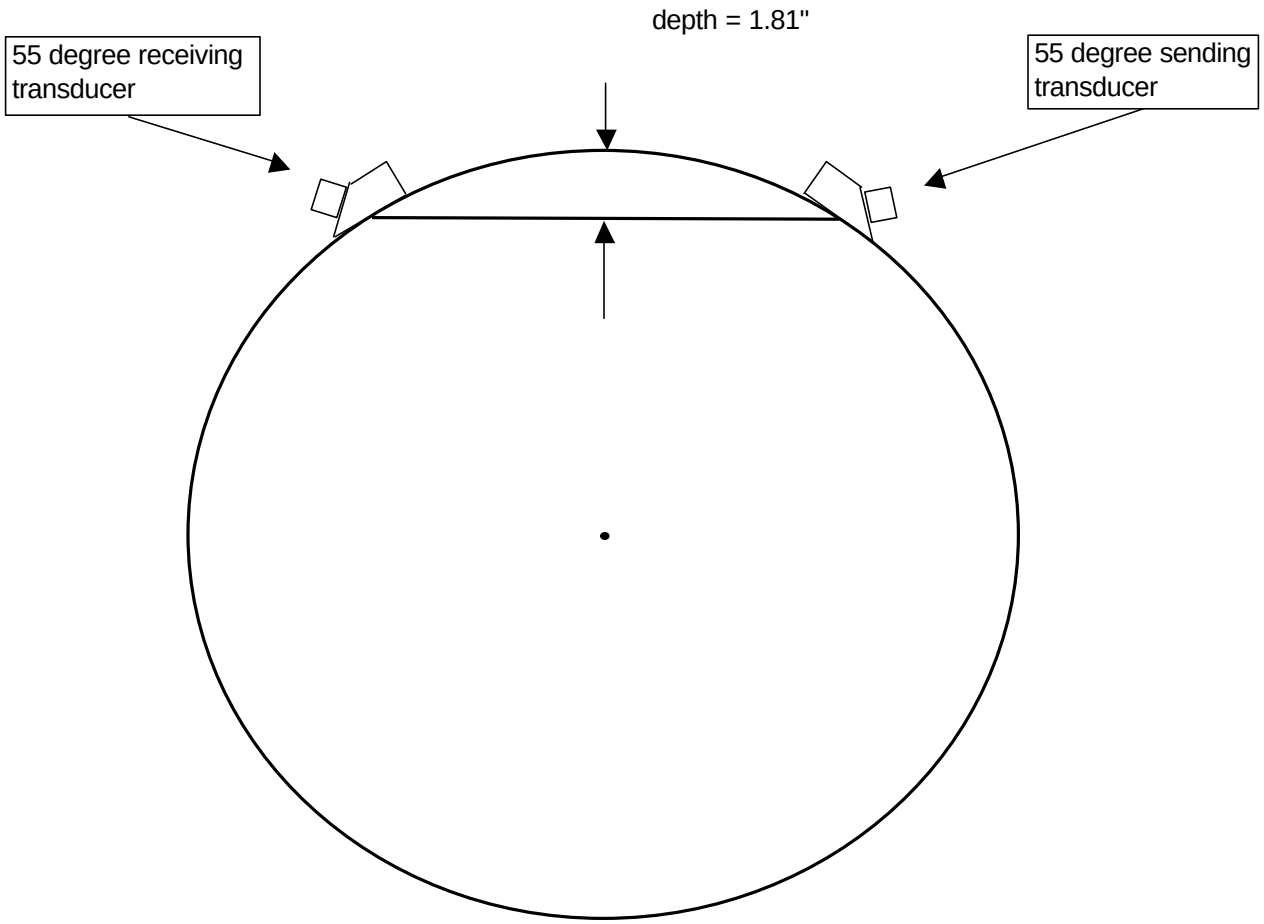
Example header is 20" diameter		D = 20"
	10" radius	R = 10"
transducer angle shown		70 degree, shear
depth as a fraction of the radius		= 0.060
depth, d, in inches		d = 0.6"



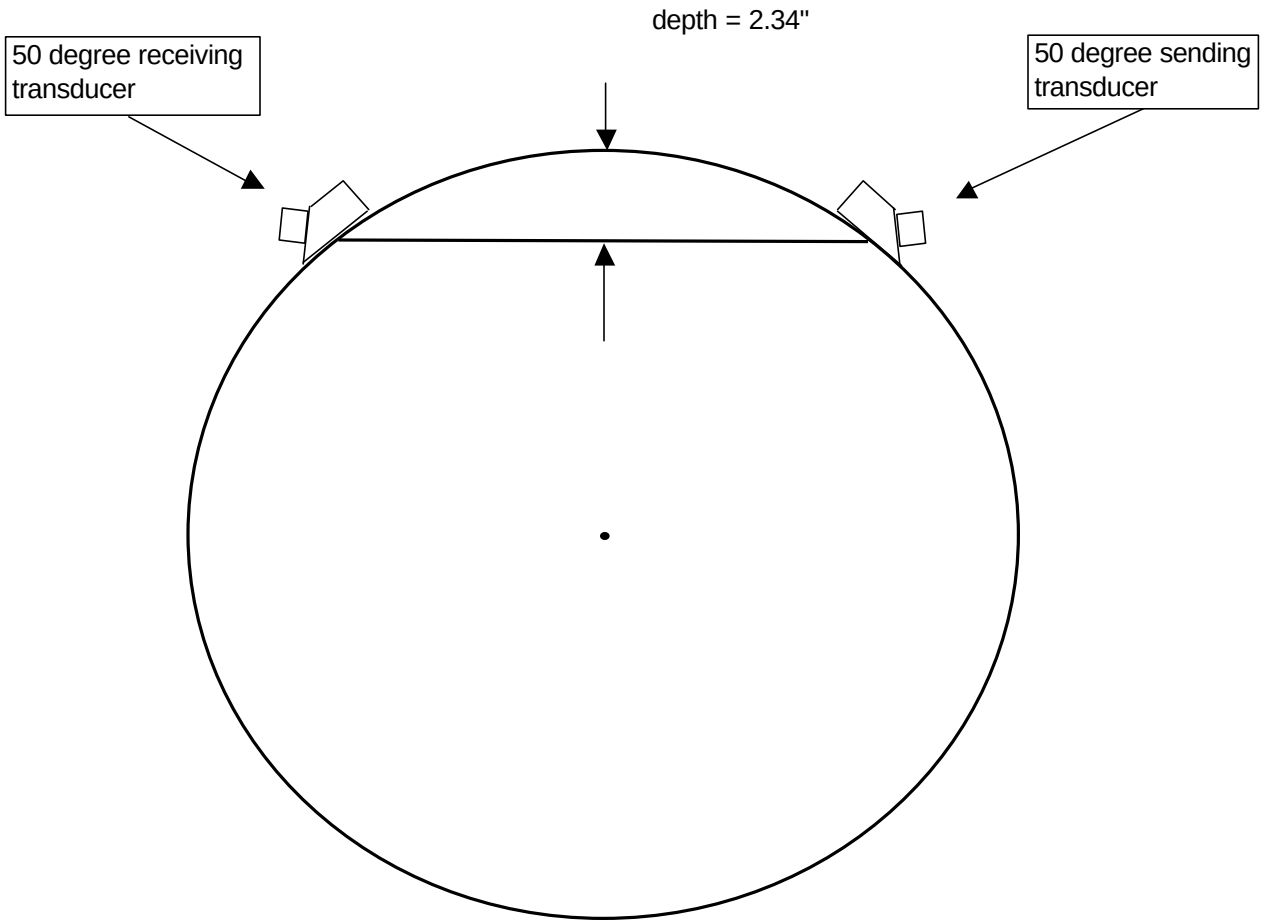
Example header is 20" diameter	D = 20"
10" radius	R = 10"
transducer angle shown	65 degree, shear
depth as a fraction of the radius	= 0.094
depth, d, in inches	d = 0.94"



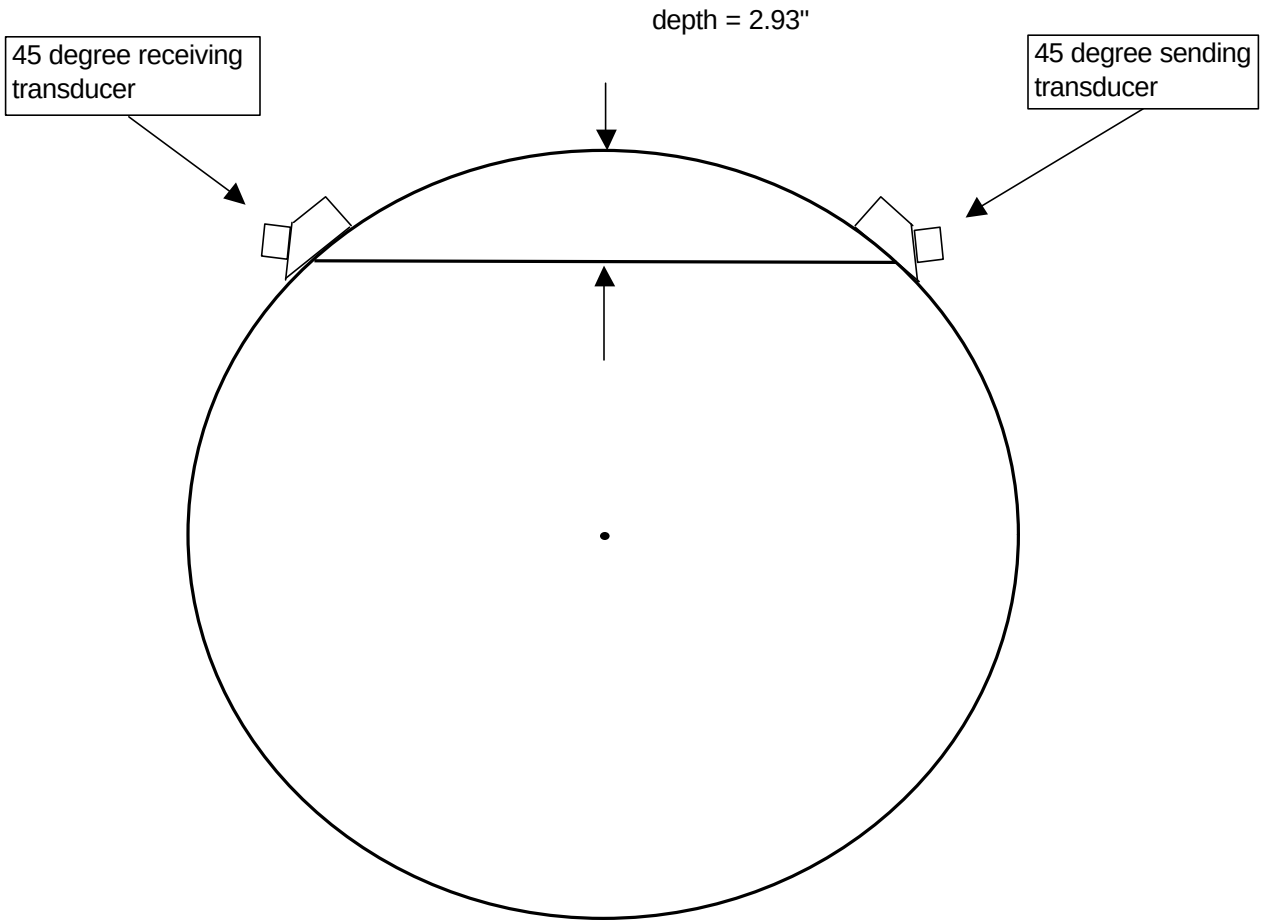
Example header is 20" diameter	D = 20"
10" radius	R = 10"
transducer angle shown	60 degree, shear
depth as a fraction of the radius	= 0.134
depth, d, in inches	d = 1.34"



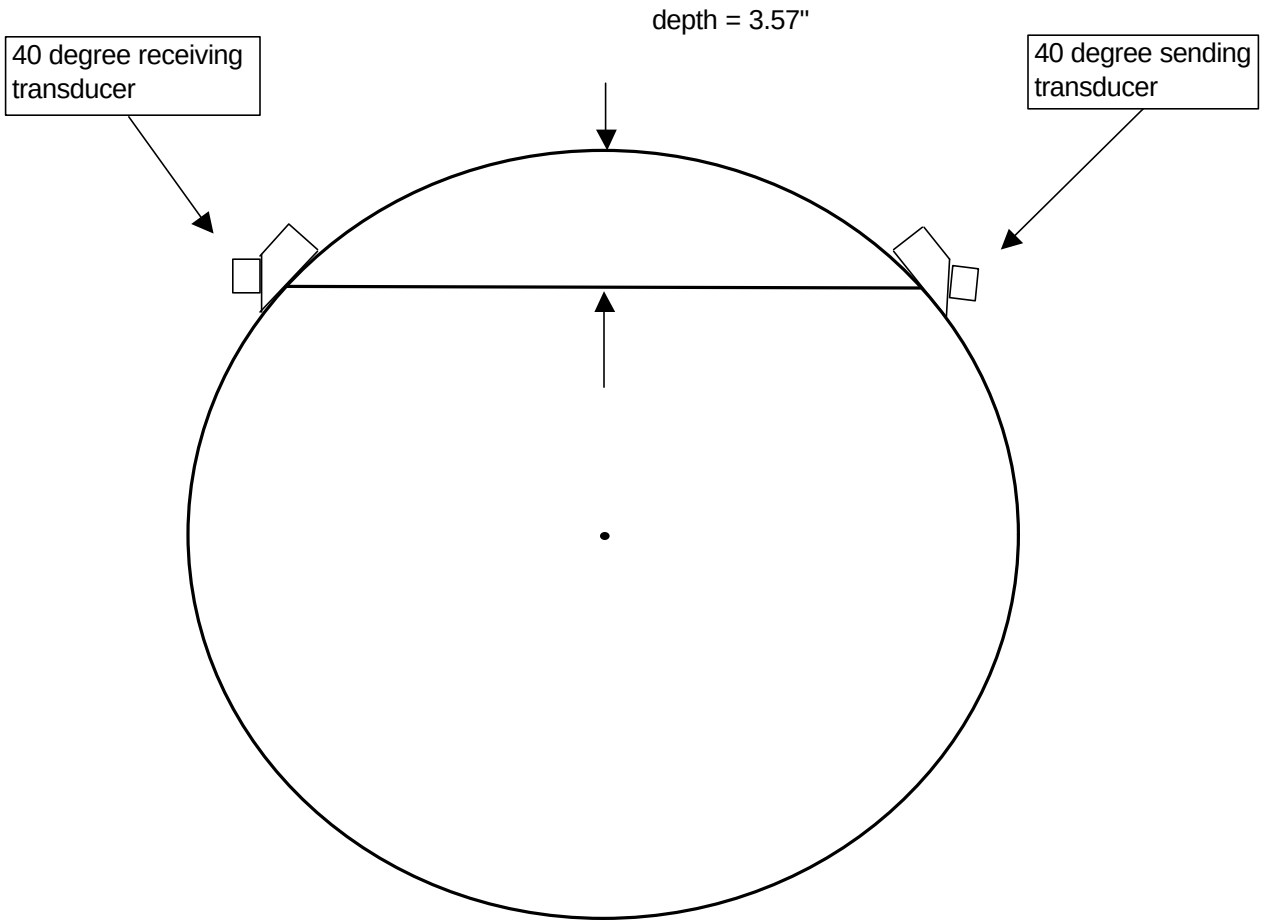
Example header is 20" diameter	D = 20"
10" radius	R = 10"
transducer angle shown	55 degree, shear
depth as a fraction of the radius	= 0.181
depth, d, in inches	d = 1.81"



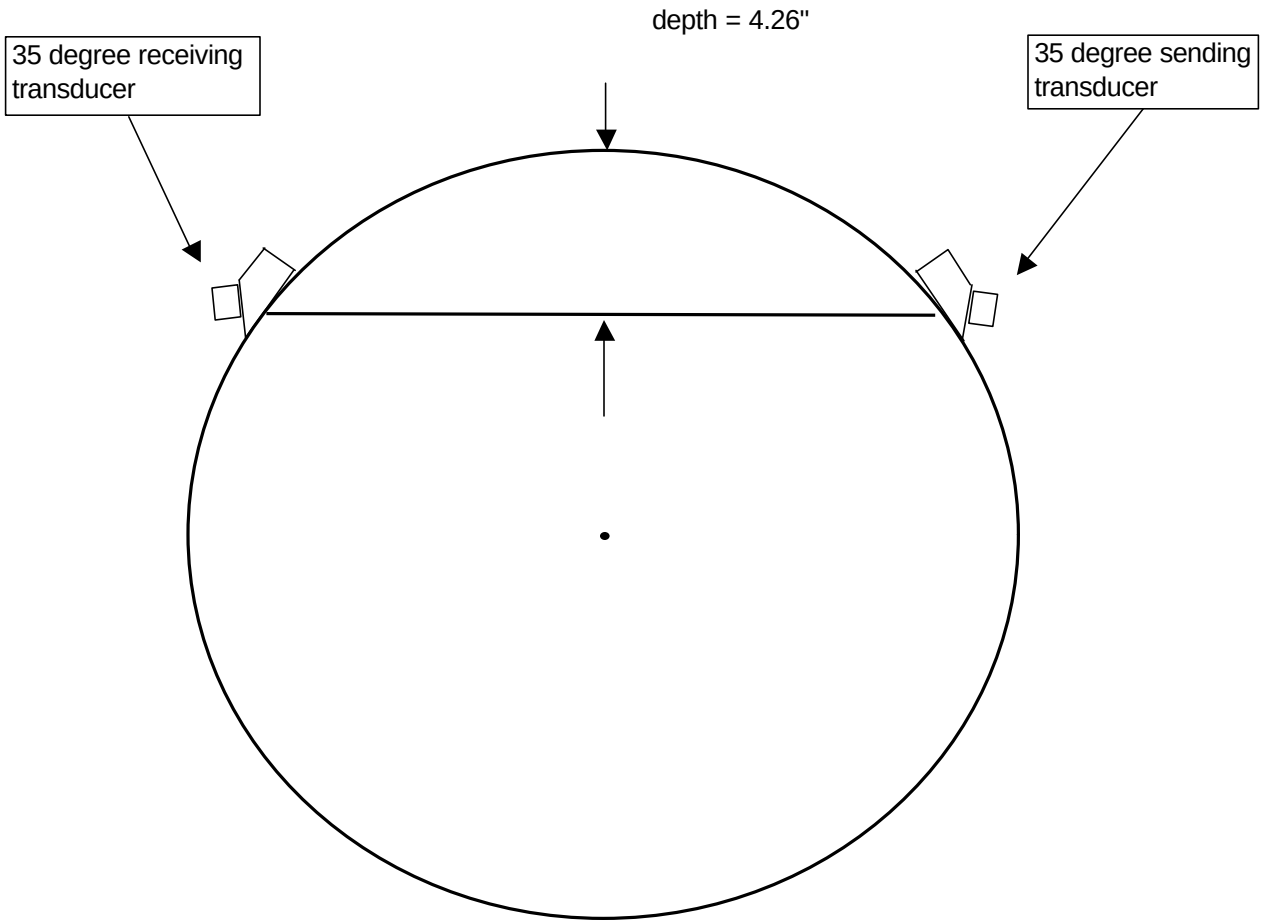
Example header is 20" diameter	D = 20"
10" radius	R = 10"
transducer angle shown	50 degree, shear
depth as a fraction of the radius	= 0.234
depth, d, in inches	d = 2.34"



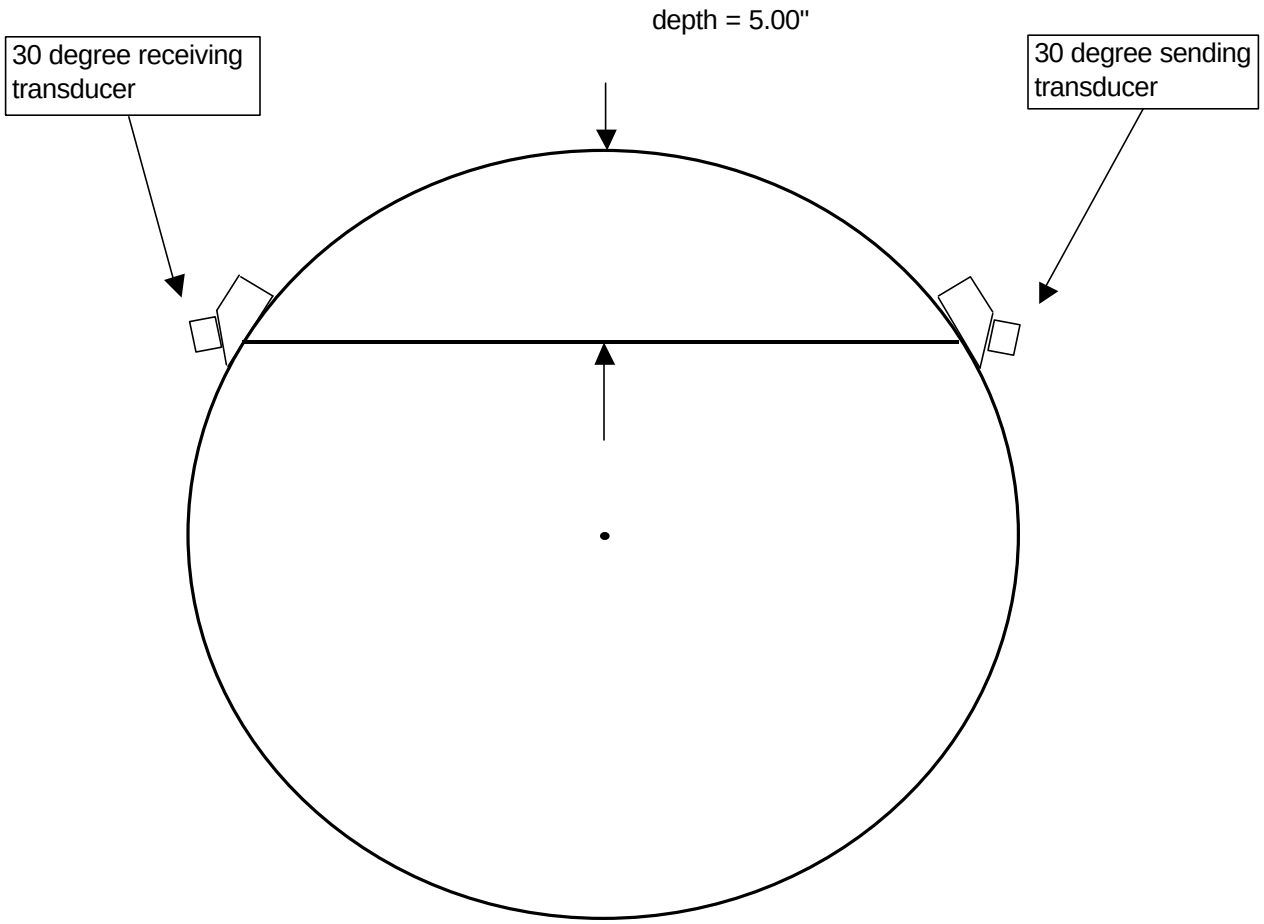
Example header is 20" diameter	D = 20"
10" radius	R = 10"
transducer angle shown	45 degree, shear
depth as a fraction of the radius	= 0.293
depth, d, in inches	d = 2.93"



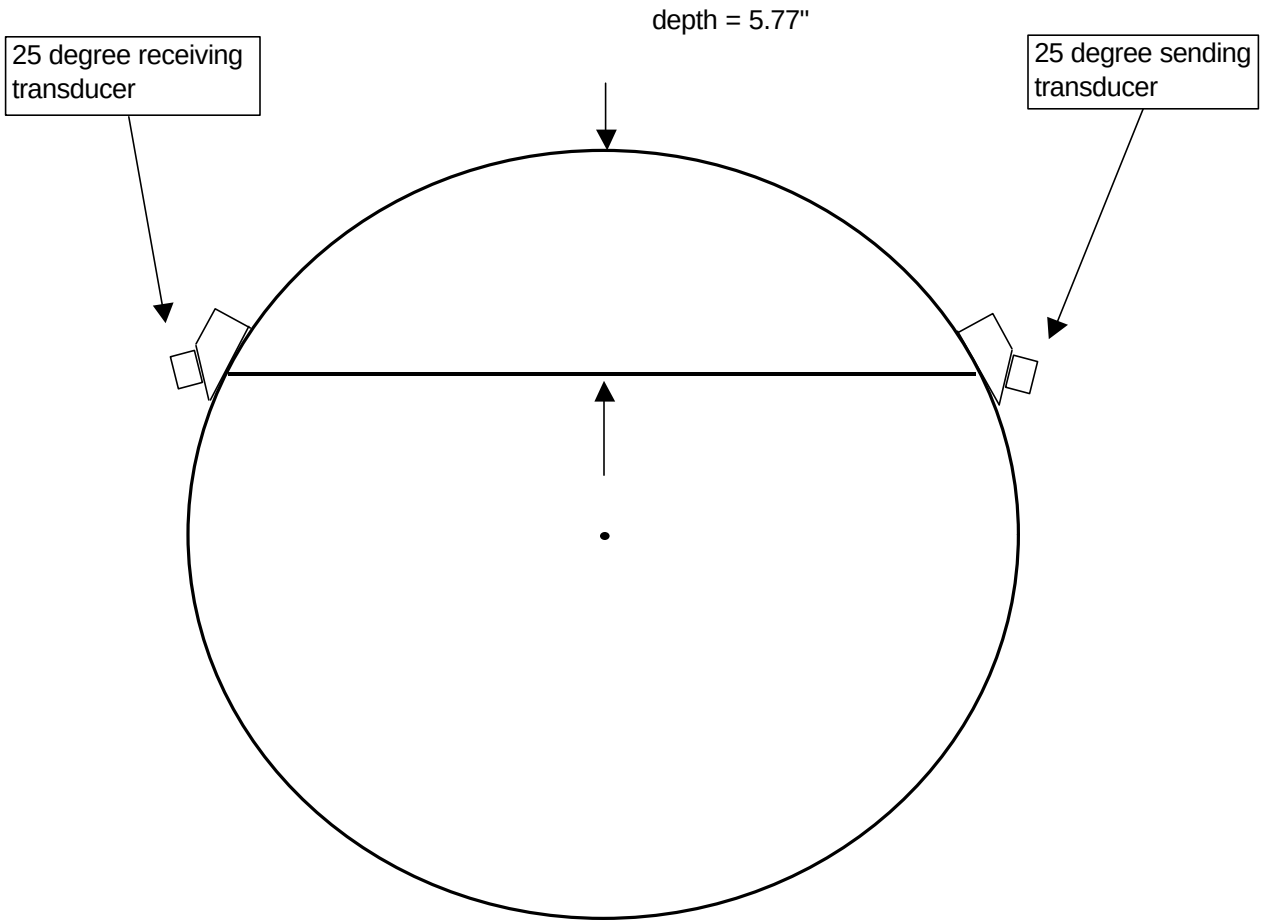
Example header is 20" diameter	D = 20"
10" radius	R = 10"
transducer angle shown	40 degree, L-wave
depth as a fraction of the radius	= 0.357
depth, d, in inches	d = 3.57"



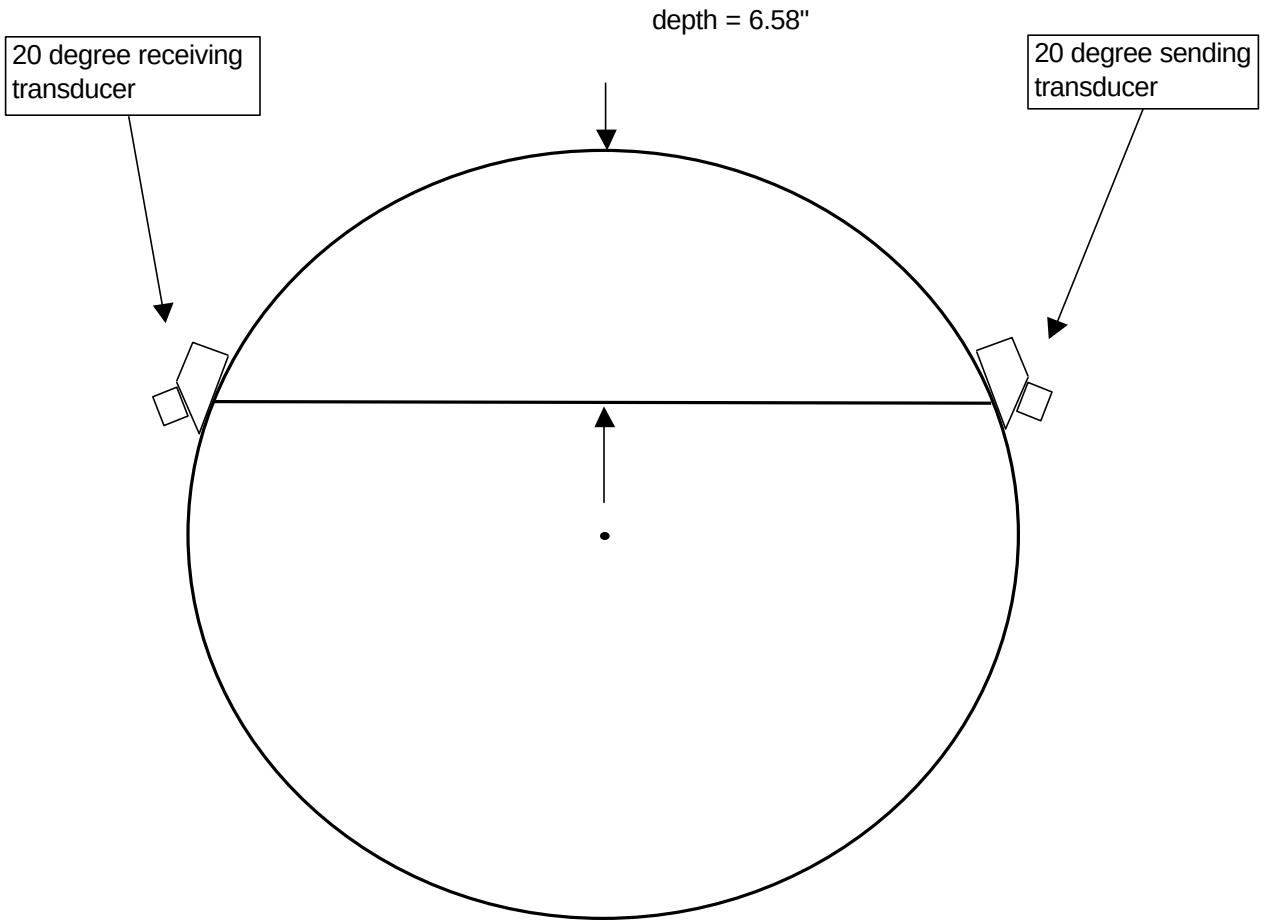
Example header is 20" diameter	D = 20"
10" radius	R = 10"
transducer angle shown	35 degree, L-wave
depth as a fraction of the radius	= 0.426
depth, d, in inches	d = 4.26"



Example header is 20" diameter		D = 20"
	10" radius	R = 10"
transducer angle shown		30 degree, L-wave
depth as a fraction of the radius		= 0.500
depth, d, in inches		d = 5.00"



Example header is 20" diameter	D = 20"
10" radius	R = 10"
transducer angle shown	25 degree, L-wave
depth as a fraction of the radius	= 0.577
depth, d, in inches	d = 5.77"



Example header is 20" diameter		D = 20"
	10" radius	R = 10"
transducer angle shown		20 degree, L-wave
depth as a fraction of the radius		= 0.658
depth, d, in inches		d = 6.58"

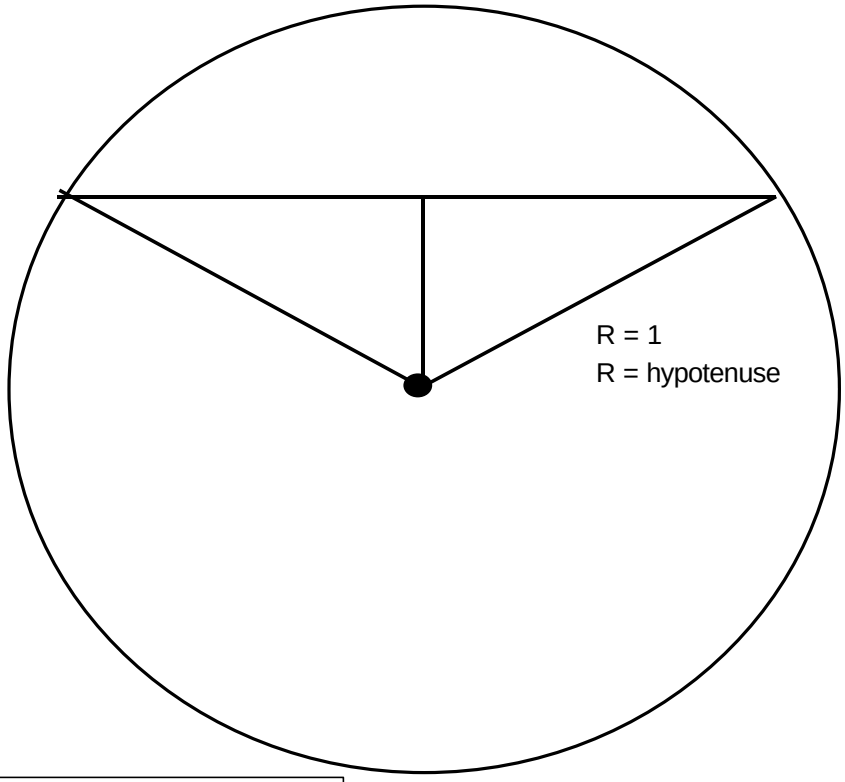
Through-Transmission Ultrasonic Calculations

Following sketches and equations show the calculations used to make a Through-Transmission set up.

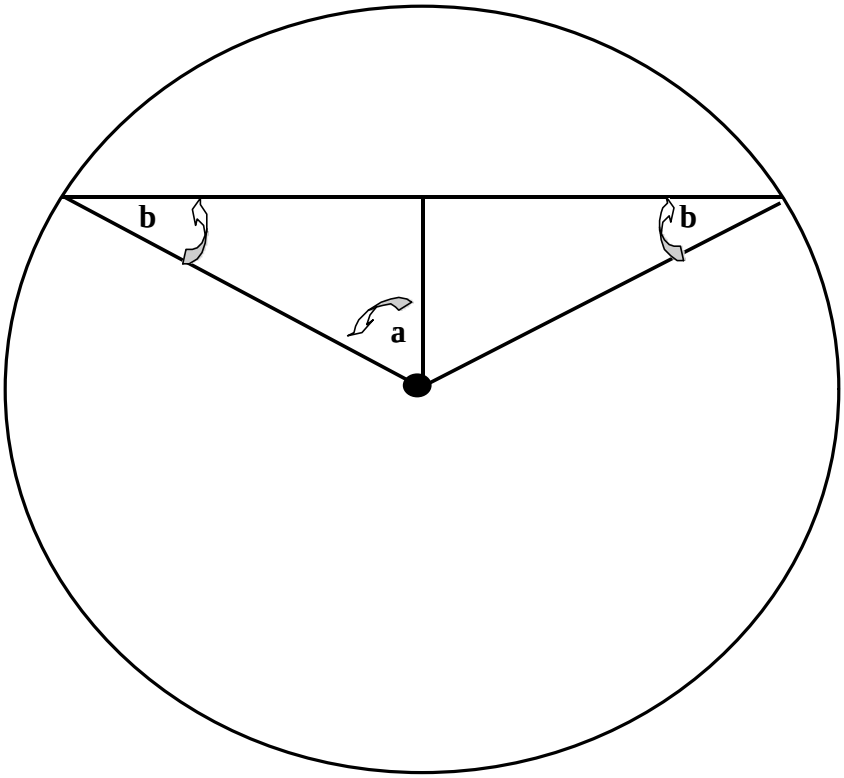
For each header the initial data known would be the header outside diameter (OD) and inside diameter (ID). This is the only data needed to calculate the set up. A drawing of the header would be needed to confirm that the preparations for the penetrations do not have unusual geometries, and to confirm the distance between the penetrations in the header.

What needs to be calculated is the circumferential distance between the transducers on the outside diameter of the header.

For detection of the ligament crack, the transducer angle is chosen that is deepest in the header without being blocked by the ID of the header.



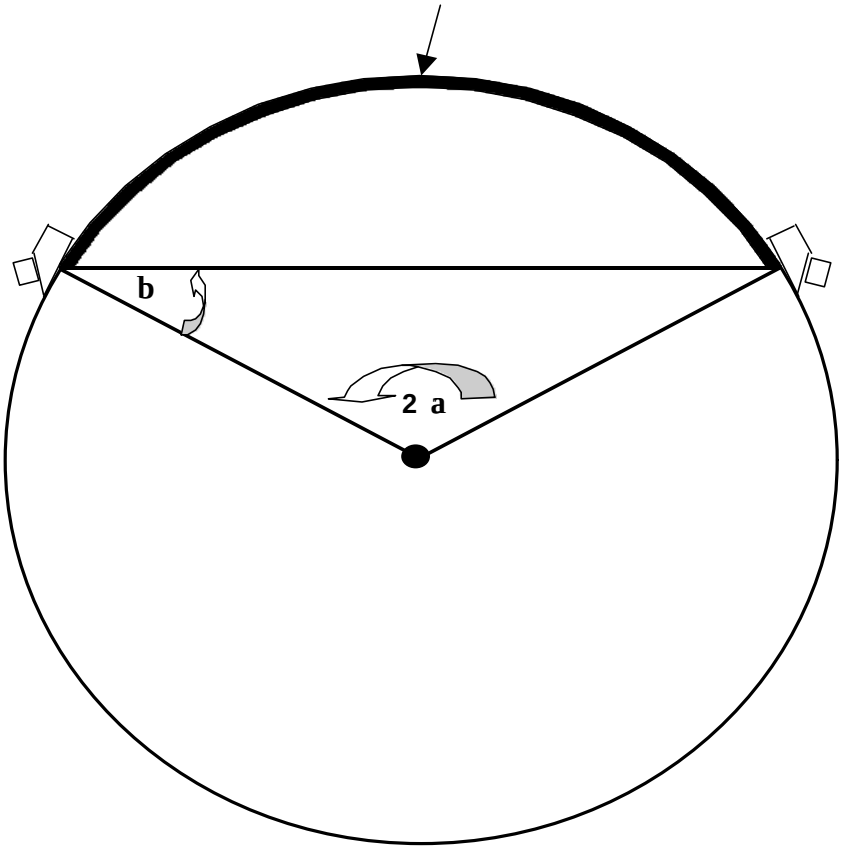
Construct 2 right triangles with a common equal side and both hypotenuse equal to the radius of the circle, which is equal to one. The resulting horizontal line is the soundpath for the Through-Transmission set-up, or can be the used as the 'Base Distance' for manual TOFD.



b = 90 - a

b = transducer angle

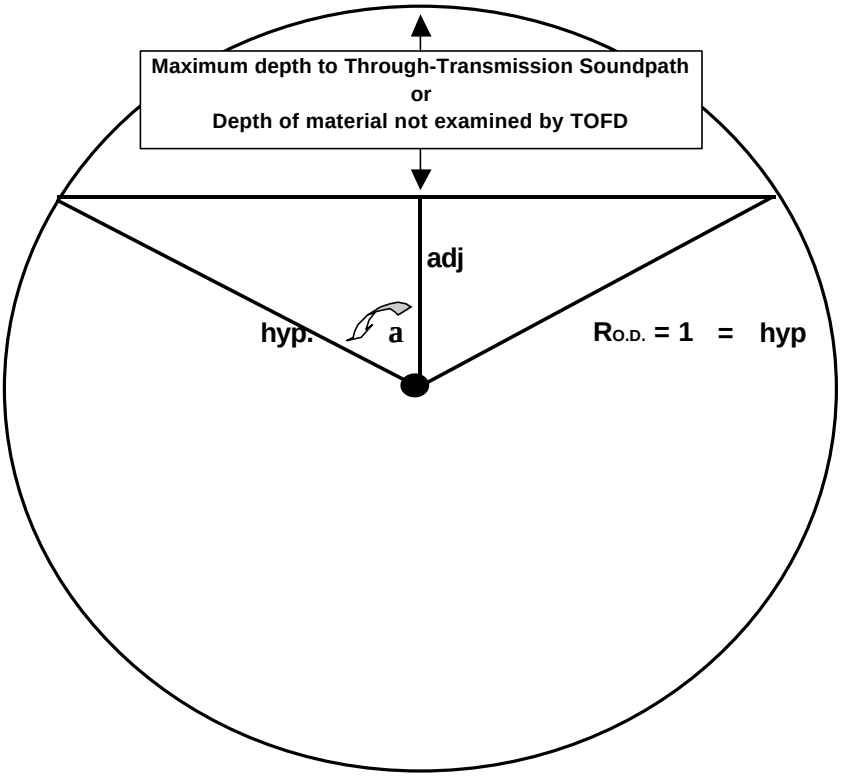
Circumferential Distance between transducers (arc distance)



included angle = 2 a

The circumference of a circle, C = p D **D = Diameter = ($R_{O.D.}$) X 2**

Circumferential Distance (arc distance) between transducers = C X $\frac{2\ a}{360}$



$$\cos a = \frac{adj}{hyp}$$

(hyp = $R_{O.D}$ = 1)

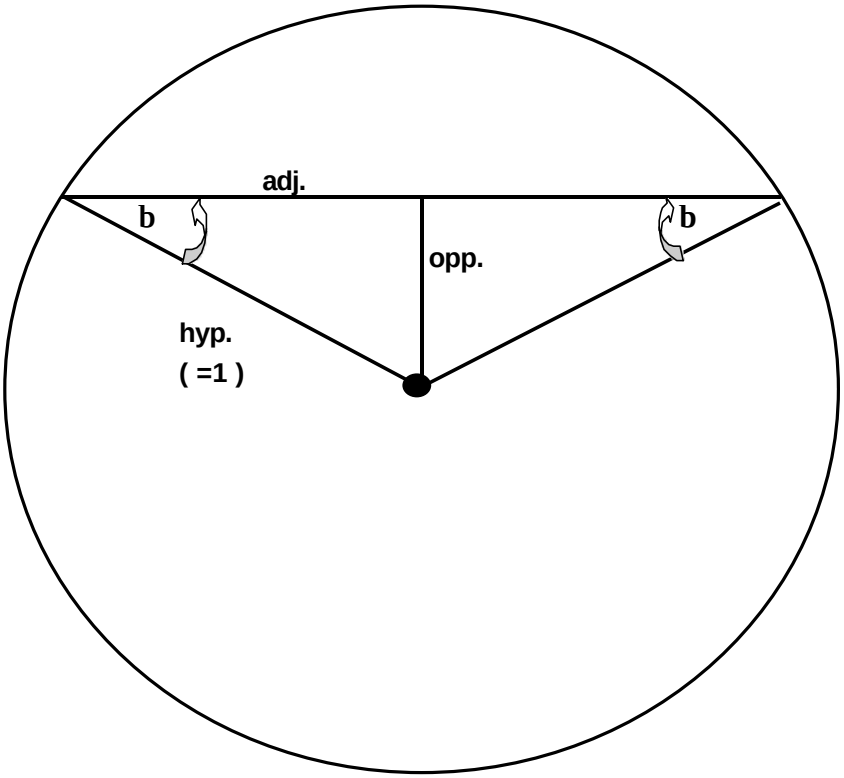
$$\cos a = \frac{adj}{1}$$

$$\cos a = adj$$

$$adj = R_{O.D.} - depth$$

$$depth = 1 - \cos a$$

(This is the depth of the material not examined by TOFD, or the maximum depth to the Through-Transmission Soundpath.)

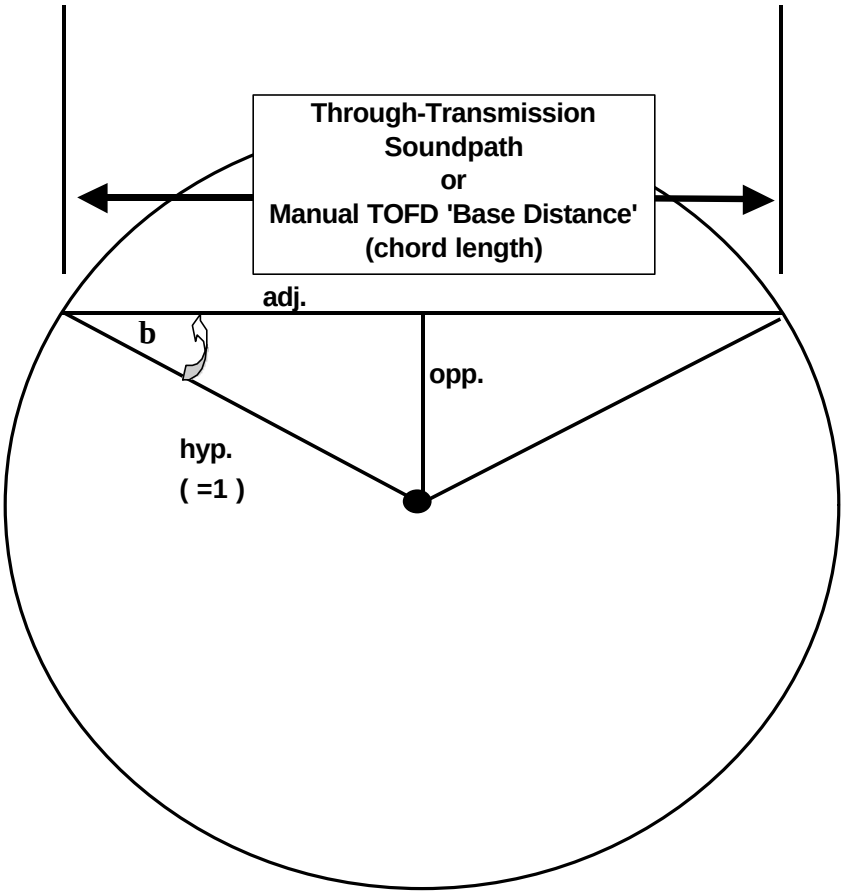


$$\cos b = \frac{\text{adj.}}{\text{hyp.}}$$

hyp. = 1

cos b = adj.

x



$$\cos b = \frac{\text{adj.}}{\text{hyp.}}$$

hyp. = 1

cos b = adj.

manual TOFD 'Base Distance' (chord length)

or

Through-Transmission Soundpath = 2 cos b (times the radius to the outer diameter)

Through-Transmission Set-Up Spreadsheet

Outside Diameter (OD)=	**20**	(insert the outside diameter in inches)							
Circumference (inches)=	62.83								
				Arc distance		Depth		Chord	
transducer angle	sound mode	included angle		Circumferential Distance (as a fraction of C)	Circumferential Distance (inches)	Depth, as a fraction of the radius	Depth (inches)		
b		**2a**	**a**	**= C X 2a / 360**		**= 1 - COSa**		**= 2 COS b X ($R_{O.D.}$)**	
70°	shear	40°	20	0.111	6.98	0.060	0.60	6.84	
65°	shear	50°	25	0.139	8.73	0.094	0.94	8.45	
60°	shear	60°	30	0.167	10.47	0.134	1.34	10.00	= 1 X $R_{O.D.}$
55°	shear	70°	35	0.194	12.22	0.181	1.81	11.47	
50°	shear	80°	40	0.222	13.96	0.234	2.34	12.86	
45°	shear	90°	45	0.250	15.71	0.293	2.93	14.14	= 1.414 X $R_{O.D.}$
40°	L-wave	100°	50	0.278	17.45	0.357	3.57	15.32	
35°	L-wave	110°	55	0.306	19.20	0.426	4.26	16.38	
30°	L-wave	120°	60	0.333	20.94	0.500	5.00	17.32	= 1.732 X $R_{O.D.}$
25°	L-wave	130°	65	0.361	22.69	0.577	5.77	18.13	
20°	L-wave	140°	70	0.389	24.43	0.658	6.58	18.79	
				(This is the distance measured between the transducers on the outside surface of the cyinder)		(This is the deepest point of the sound beam centerline in the part)		(This is the soundpath length in inches through the material)	

Manual TOFD

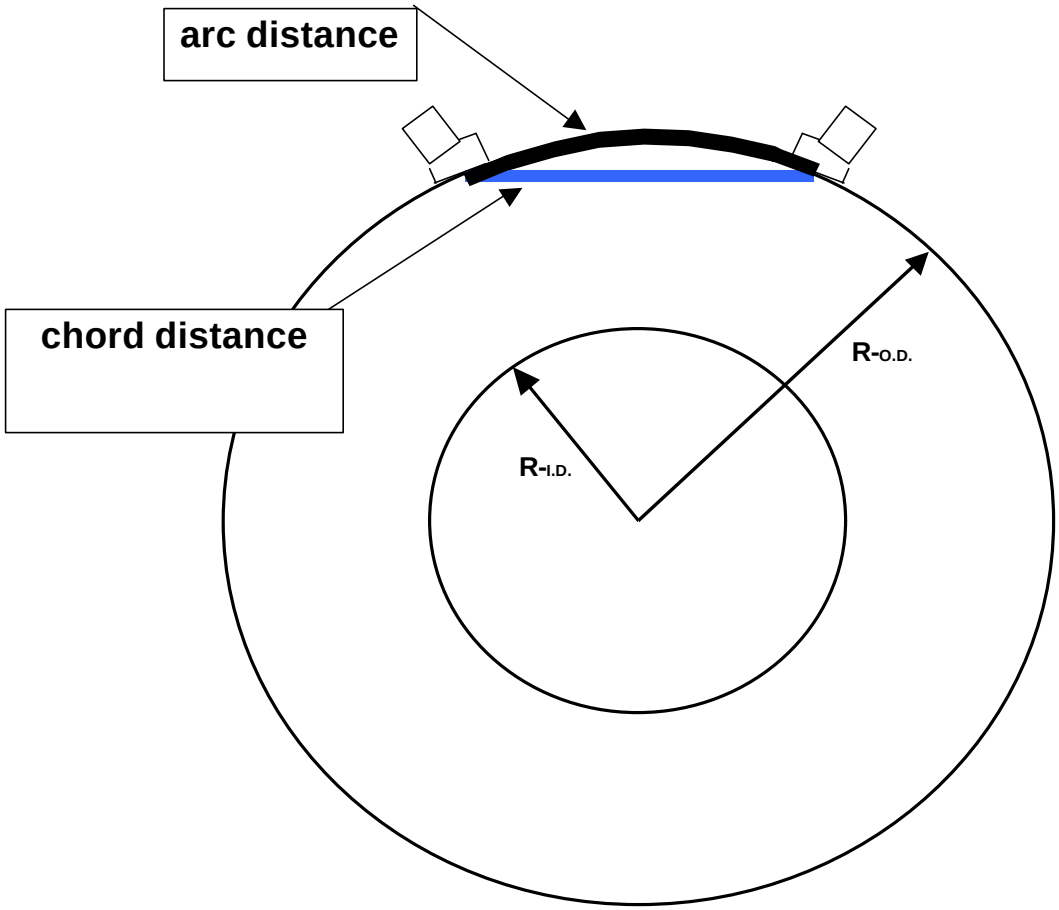
Manual TOFD of axial cracks uses radial oriented transducers in pitch-catch pairs. The transducer pair can scan axially, or circumferentially.

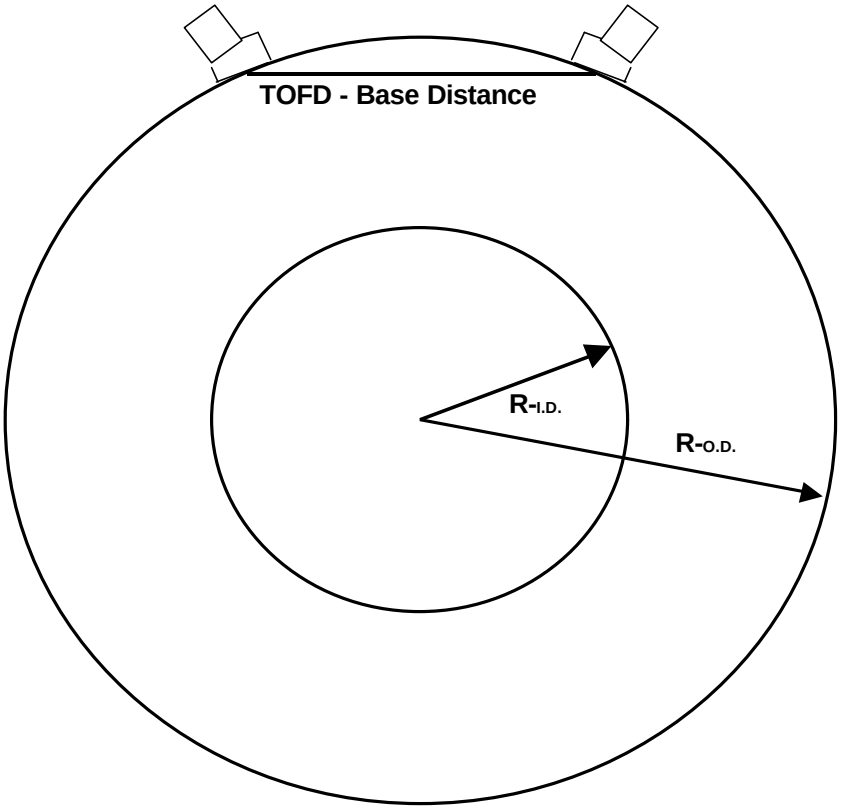
The previous set-up shown for TOFD on flat surfaces is adapted for cylindrical shaped scanning surfaces. The only difference being that the 'Base Distance' lies on a chord within the volume of the material. The same Excel spreadsheets previously shown for flat plate are adapted for sizing of axial cracks.

The following sketches show some of the relations of 'Base Distance', 'L-Distance', chord length and arc or circumferential length.

Then the basis for calculations of 'Base-Distance' and circumferential distance are shown.

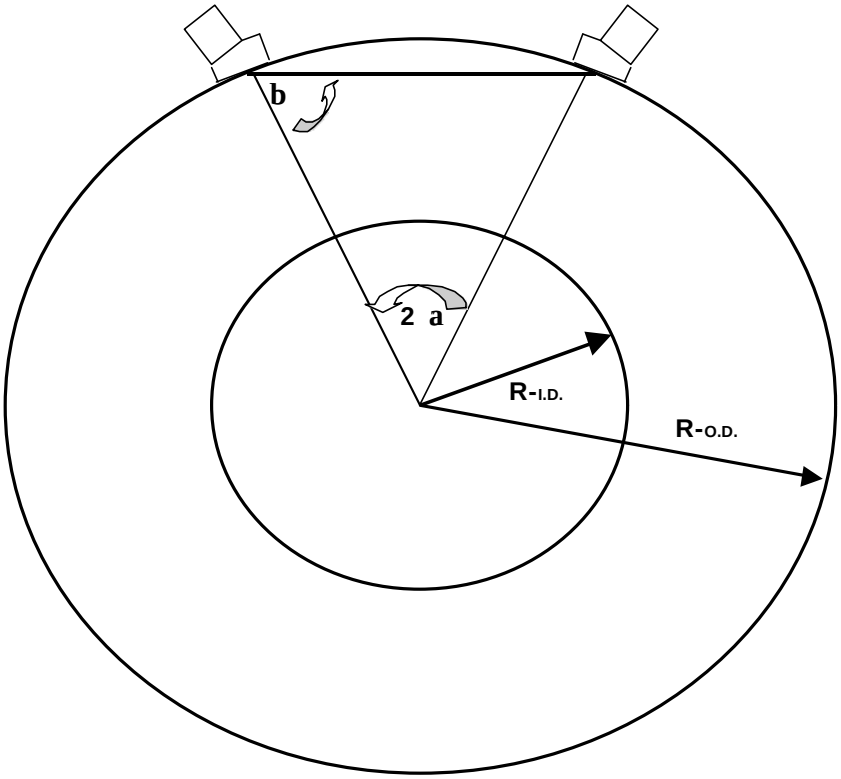
The final spreadsheet is the spreadsheet used for set-up of manual TOFD on cylindrical scanning surfaces.


arc distance
chord distance
R-O.D.
R-I.D.



$R_{O.D.}$ = Radius to the Outer Diameter of the pipe, header or cylinder

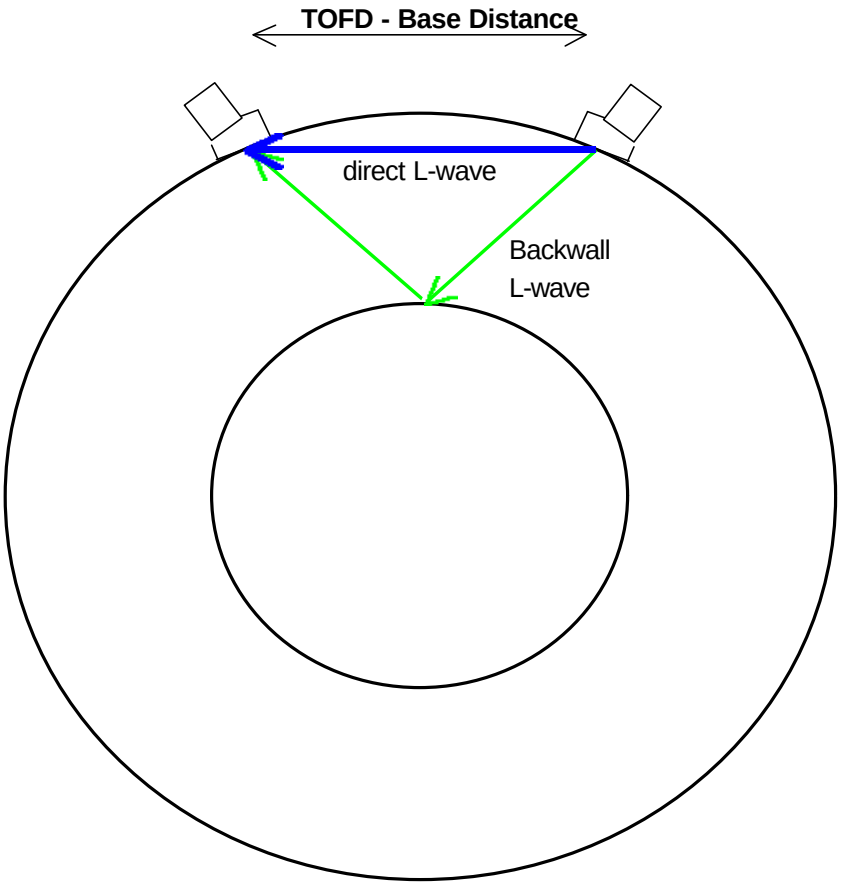
$R_{I.D.}$ = Radius to the Inner Diameter of the pipe, header or cylinder

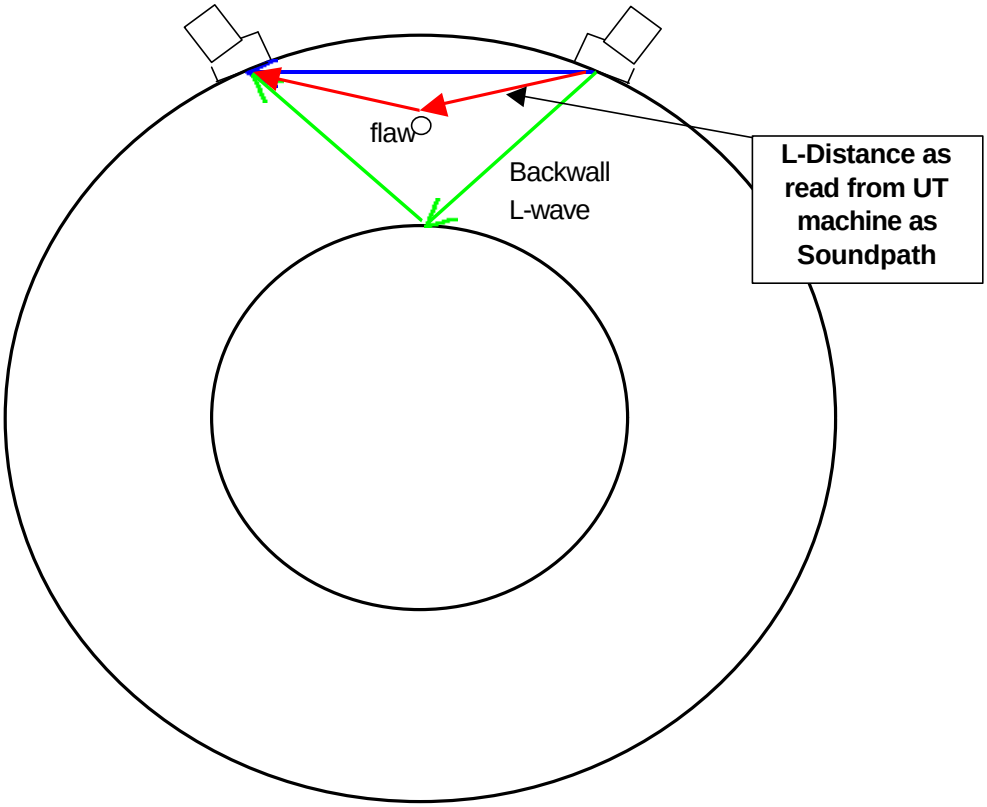


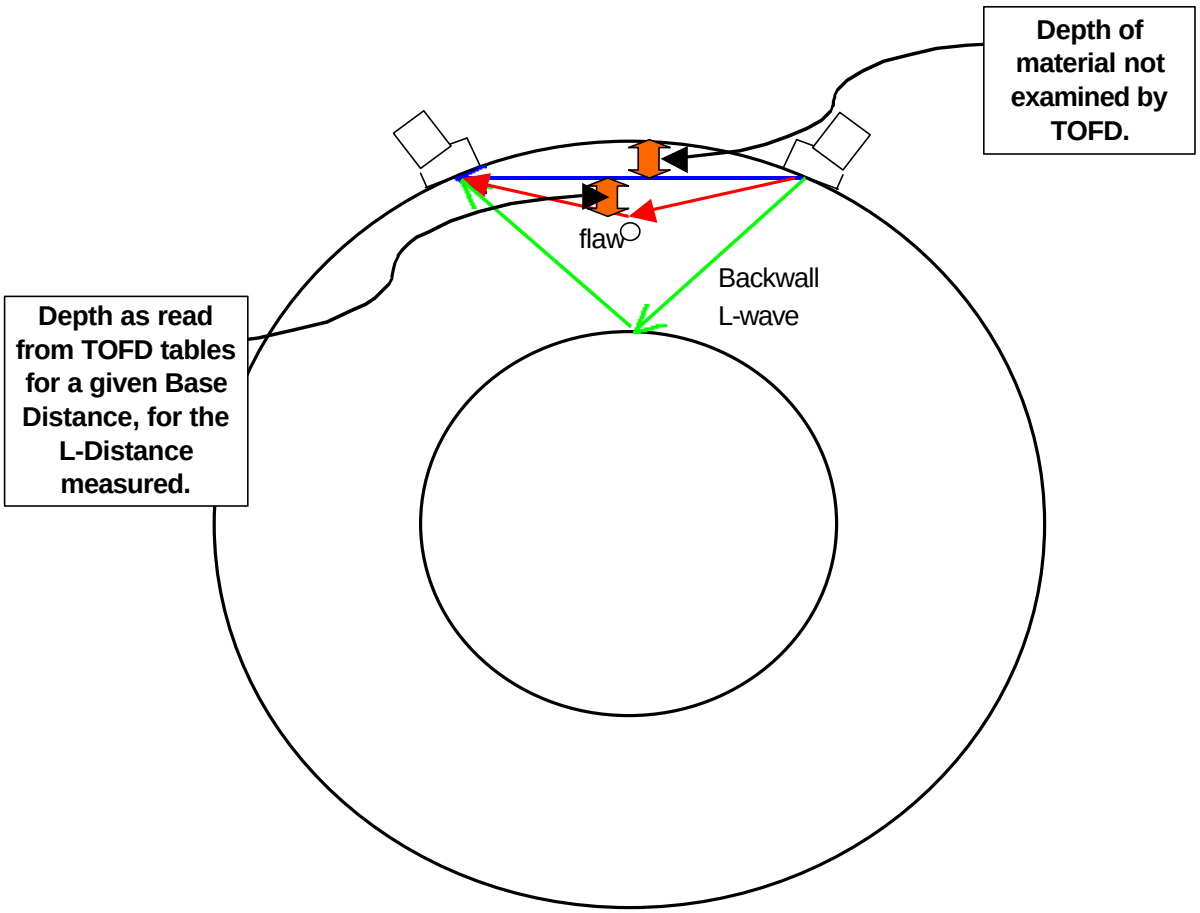
b = base-to-radial angle (this was the transducer angle for thru-transmission testing)

2 a = included angle

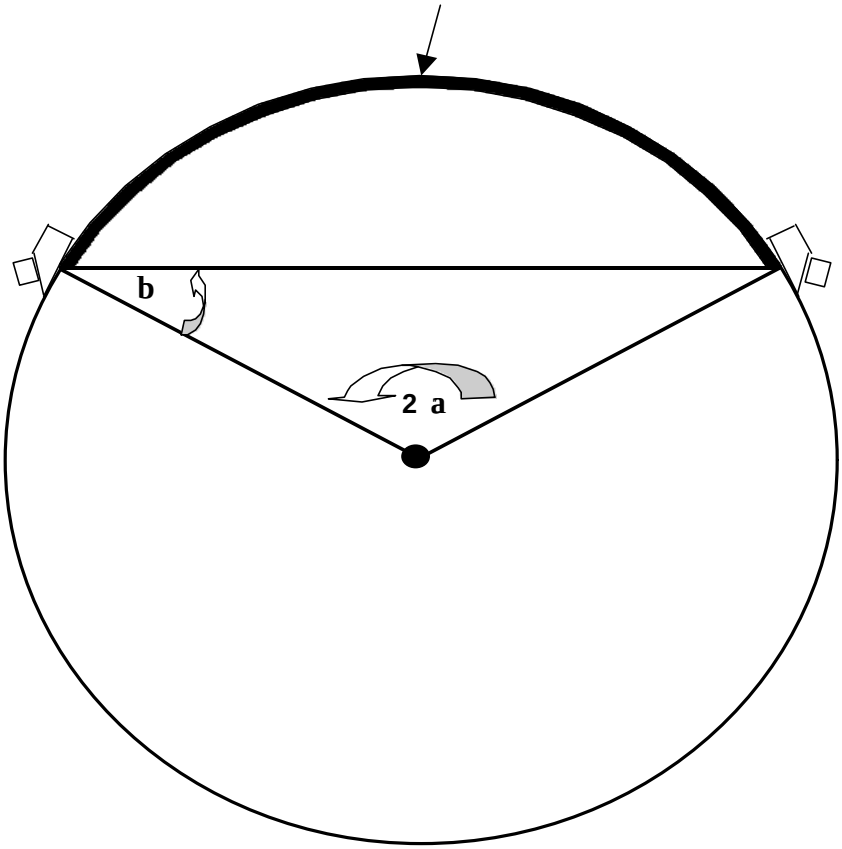
x


TOFD - Base Distance
direct L-wave
Backwall
L-wave


flaw
Backwall
L-wave
L-Distance as read from UT machine as Soundpath


Depth of material not examined by TOFD.
flaw
Backwall
L-wave
Depth as read from TOFD tables for a given Base Distance, for the L-Distance measured.

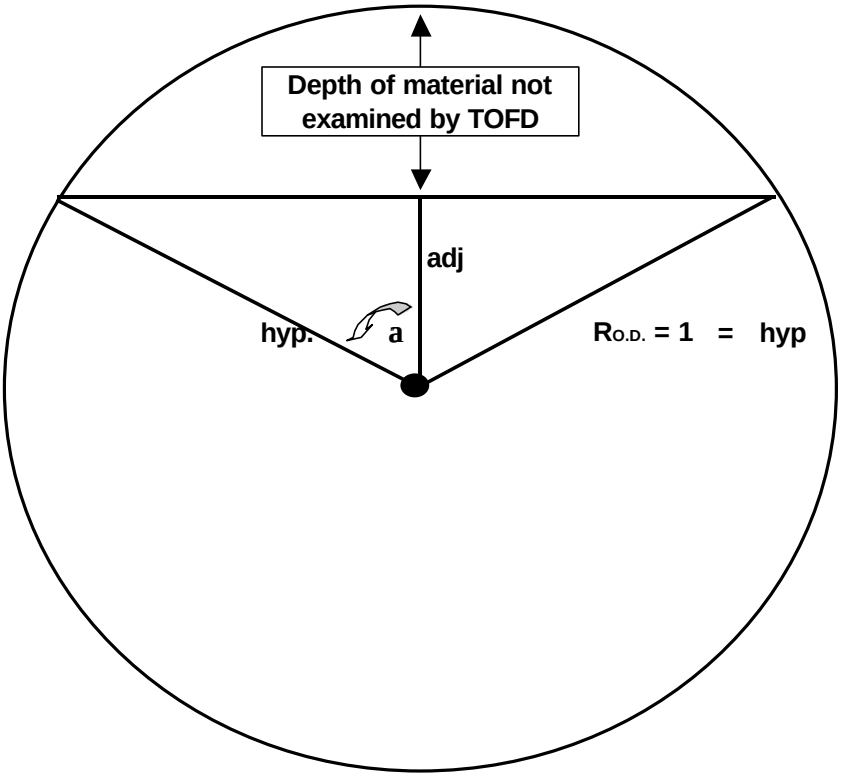
Circumferential Distance between transducers (arc distance)



included angle = 2 a

The circumference of a circle, C = p D **D = Diameter = 2 X $R_{O.D.}$**

Circumferential Distance (arc distance) between transducers = C X $\frac{2\ a}{360}$



$$\cos a = \frac{adj}{hyp}$$

(hyp = $R_{O.D}$ = 1)

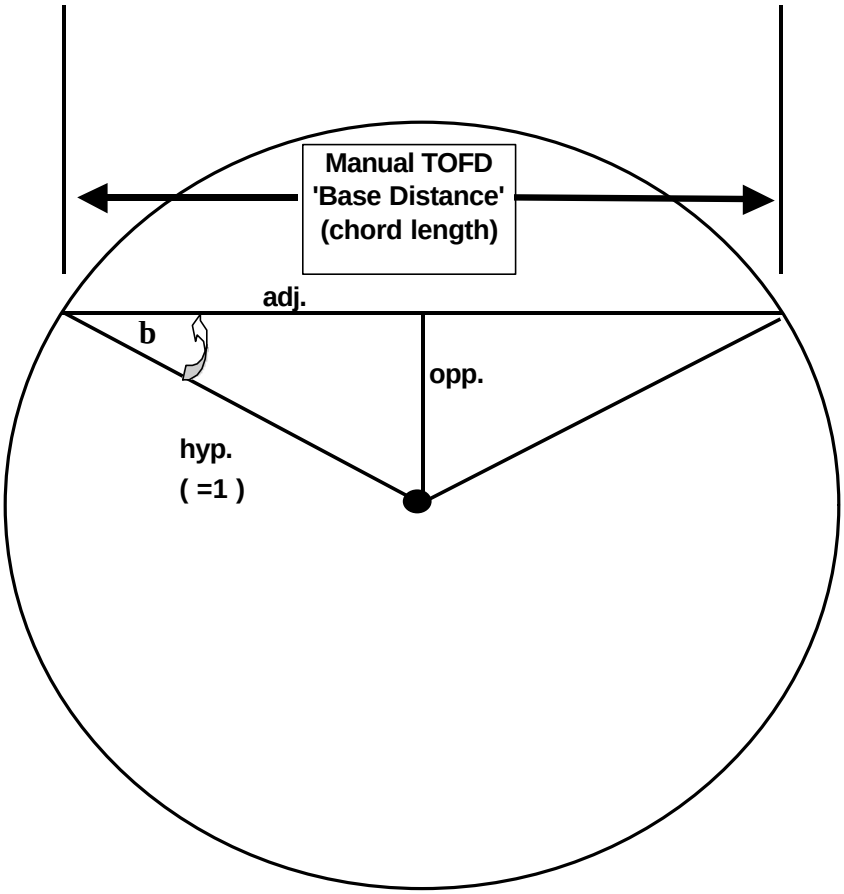
$$\cos a = \frac{adj}{1}$$

$$\cos a = adj$$

$$adj = R_{O.D.} - depth$$

$$depth = 1 - \cos a$$

(This is the depth of the material not examined by TOFD.)



$\cos b = \frac{\text{adj.}}{\text{hyp.}}$

hyp. = 1

$\cos b =$ adj.

manual TOFD 'Base Distance' (chord length)= 2 cos b (times the radius to the outer diameter)

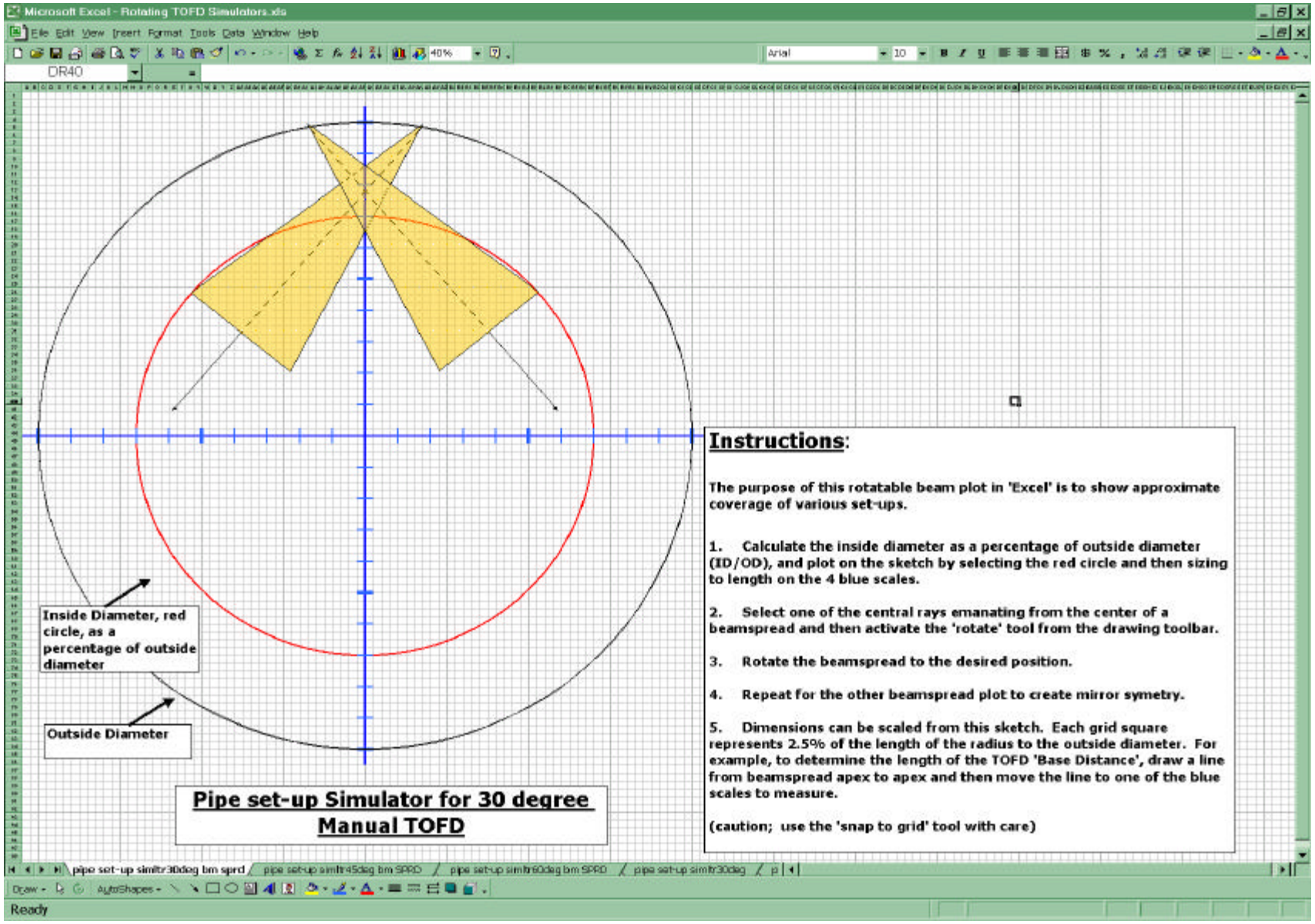
Radial TOFD Set-Up Spreadsheet for Pipe, Headers or Cylinders

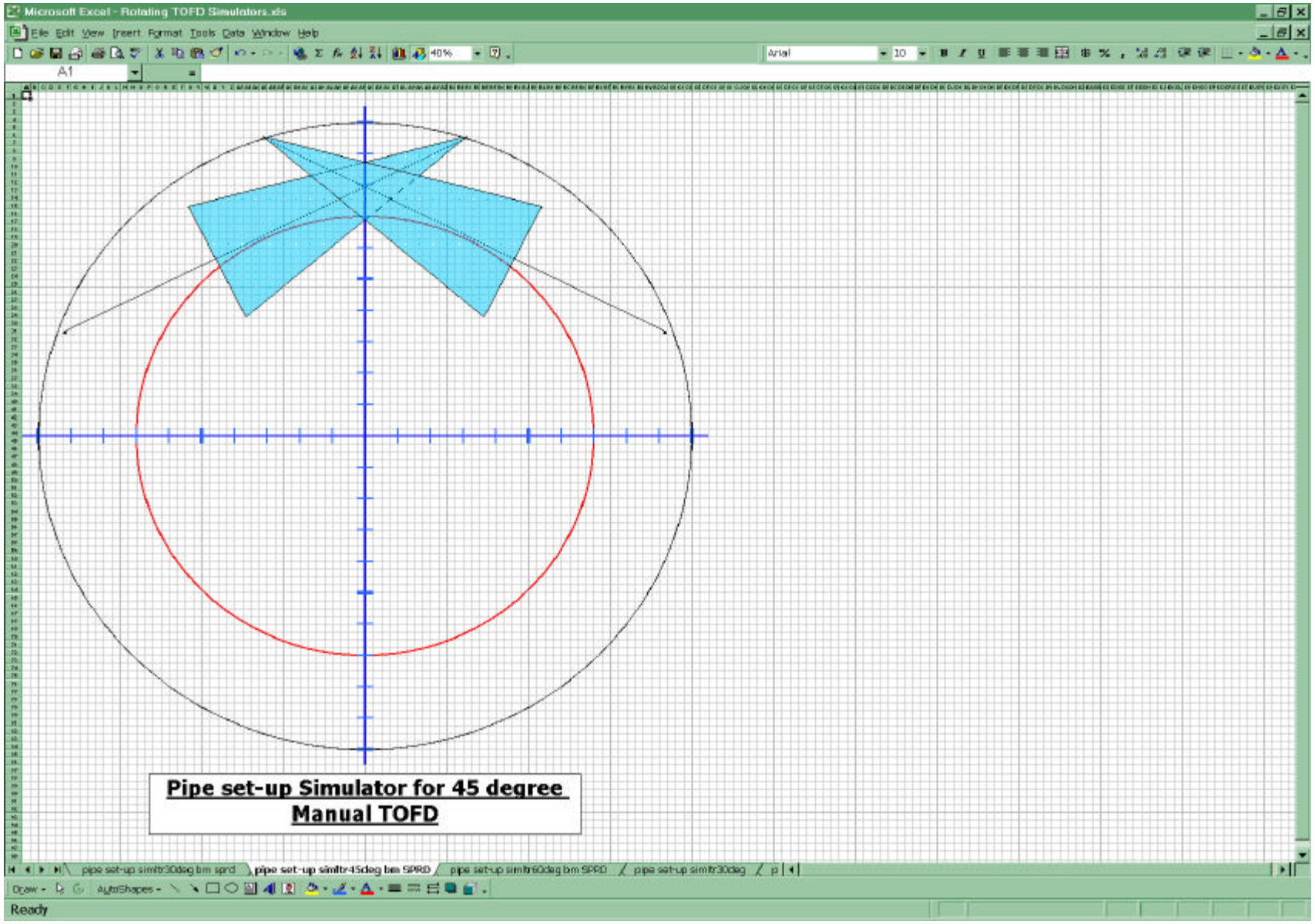
Base Distance =	**4**	(insert the Base Distance or chord, inches)						
Outside Diameter (OD)=	**20**	(insert the outside diameter in inches)			**$R_{O.D.}$ =**	**10**		
Inside Diameter (OD)=	**16**	(insert the inside diameter in inches)			**$R_{I.D.}$ =**	**8**		
circumference (inches)=	62.83							
				Arc distance		Depth		
base to radial angle (degrees)		included angle (degrees)		Circumferential Distance (as a fraction of C)	Circumferential Distance (inches)	Depth, as a fraction of the radius	Depth (inches)	Depth to ID of the TOFD 'Backwall L-wave'
b		**2a**	**a**	**= 2a / 360**	**= C X 2a / 360**	**= 1 - COSa**		
78.46		23.07	11.54	0.064	4.03	0.020	0.20	1.80
				(This is the distance measured between the transducers on the outside surface of the cyinder)		(This is the depth of material not examined by TOFD)		

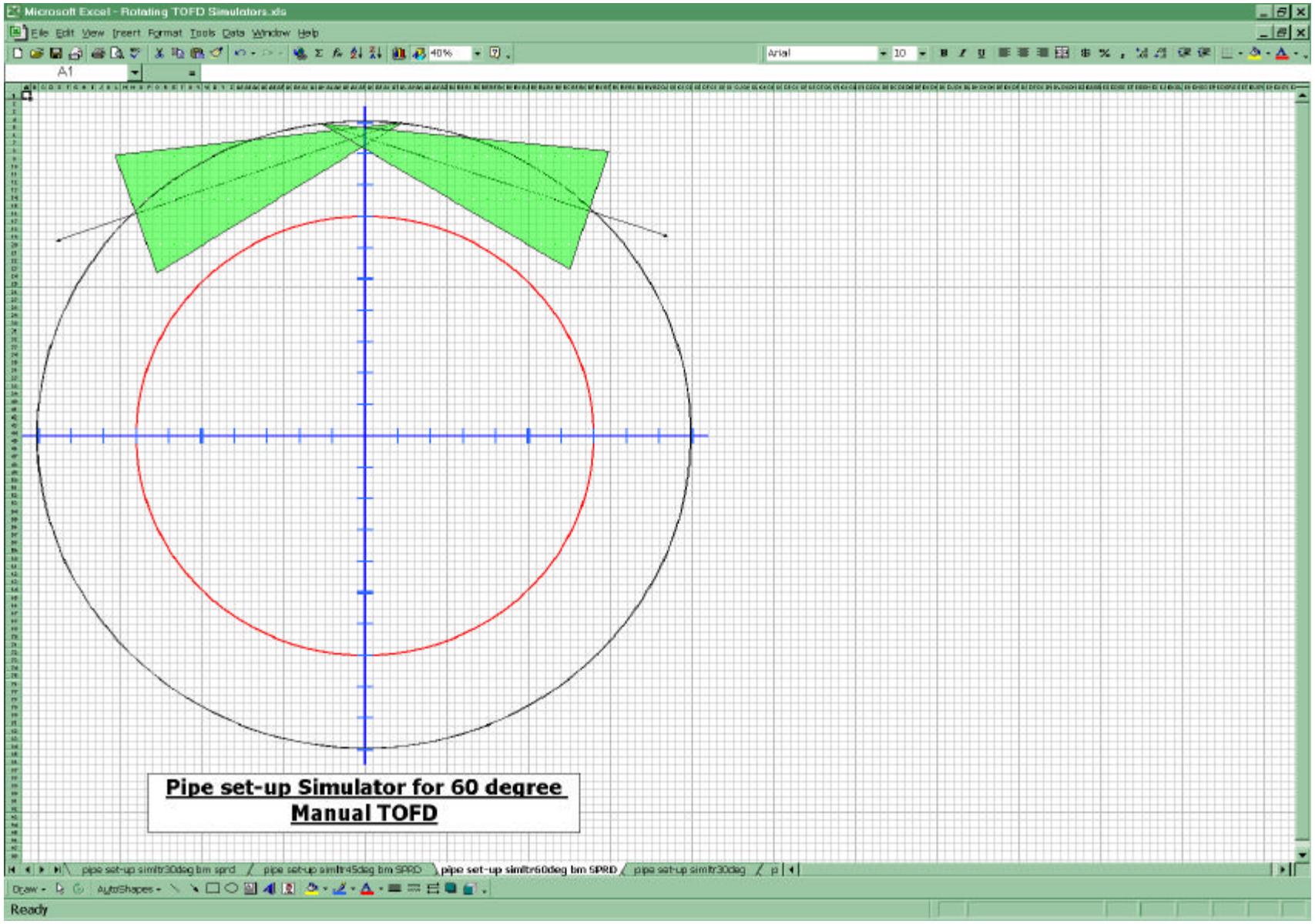
Circumferentially Oriented Manual TOFD Simulators

Three Excel spreadsheets have been made which can simulate TOFD set-ups with various base distances for an infinite variety of pipe OD and ID combinations. The beam-spreads of 30 degree L-wave, 45 degree L-wave, and 60 degree L-wave are shown on separate spreadsheets.

Three 'print-screens' of the spreadsheets follow as examples of what they look like.


Microsoft Excel - Rotating TOFD Simulators.xls
File Edit View Insert Format Tools Data Window Help
DR40
Inside Diameter, red circle, as a percentage of outside diameter
Outside Diameter
Pipe set-up Simulator for 30 degree Manual TOFD
Instructions:
The purpose of this rotatable beam plot in 'Excel' is to show approximate coverage of various set-ups.
1. Calculate the inside diameter as a percentage of outside diameter (ID/OD), and plot on the sketch by selecting the red circle and then sizing to length on the 4 blue scales.
2. Select one of the central rays emanating from the center of a beamspread and then activate the 'rotate' tool from the drawing toolbar.
3. Rotate the beamspread to the desired position.
4. Repeat for the other beamspread plot to create mirror symetry.
5. Dimensions can be scaled from this sketch. Each grid square represents 2.5% of the length of the radius to the outside diameter. For example, to determine the length of the TOFD 'Base Distance', draw a line from beamspread apex to apex and then move the line to one of the blue scales to measure.
(caution; use the 'snap to grid' tool with care)
Ready


Microsoft Excel - Rotating TOFD Simulators.xls
File Edit View Insert Format Tools Data Window Help
A1
Pipe set-up Simulator for 45 degree
Manual TOFD
Ready


Microsoft Excel - Rotating TOFD Simulators.xls
File Edit View Insert Format Tools Data Window Help
A1
Pipe set-up Simulator for 60 degree
Manual TOFD
pipe set-up simltr30deg bm sprd
pipe set-up simltr45deg bm SPRD
pipe set-up simltr60deg bm SPRD
pipe set-up simltr30deg
Draw
AutoShapes
Ready