

FAST™ Ultrasonics

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Abstract

The method discussed in this paper uses a simple and concise procedure which is effective and efficient for locating tip diffracted signals. The technique uses refracted longitudinal waves to both detect and size planar flaws.

The confusion which is traditionally associated with angled L-wave techniques, due to mode conversion and direct shear wave reflections, is virtually eliminated, while enhancing the ability to detect tip signals by using the *FASTÔ* technique. This technique increases the speed of detection and simplifies sizing compared to traditional shear wave examinations and/or other advanced techniques. *FASTÔ* is an acronym for *Flaw Analysis and Sizing Technique*.

Historical Perspective

Shear waves have been traditionally used for weld examinations. When properly applied, they work well for locating most flaws. Inspection specifications promote the use of shear wave in ultrasonic weld examinations. Until recently there were no alternatives to the basic amplitude based shear wave examinations.

Examination specifications typically use acceptance criteria and/or reflector evaluation criteria based upon the amplitude responses from known reflectors in a specific calibration block. These techniques have deficiencies when it comes to assessing the severity of service generated flaws. The flaws of concern are typically planar cracks emanating from the inside surface of piping welds.

The use of amplitude based criteria for the assessment of cracking has been carefully studied for the past fifteen years. One of the industries most severely affected by amplitude based flaw assessment is the US Nuclear power generation industry.

Due to well documented problems with amplitude based ultrasonic examinations of piping welds containing IGSCC, the US nuclear industry has been required to use examiners who have enhanced training and qualification to inspect welds subject to IGSCC. The training provides examiners with the logic needed to assess IGSCC without using signal amplitude as a criteria. This enhanced training and qualification has been underway in the US since the mid 1980's.

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Included in this training, among other things, is the use of refracted L-wave examinations for characterization and confirmation of suspected flaws. Typically the primary examination is performed using shear waves with only those areas flagged as suspect requiring further investigation by the L-waves and/or other advanced characterization techniques. Improved techniques, enhanced inspector training and qualification programs for examiners has improved the inspections being performed.

However, problems with these approaches still persist. The shear wave techniques produce so many reflections from inside surface conditions that examiners can be overwhelmed trying to sort out those indications from real flaws. Missed cracks and incorrect crack calls can, and do, result.

Inconsistent data is frequently generated from different examiners who have inspected the same weld. Similar inconsistencies can happen with the same examiner inspecting the same weld at different times. The advanced inspection techniques can also provide inconsistent results from technique to technique in an area under evaluation. Automated UT examinations, radiography and other techniques can be very helpful in resolving some indications. However, even when these techniques are applied in accordance with an acceptable procedure, different conclusions can still be reached, even between examiners of apparent equal capability.

The roots of traditional techniques go back to various “Code” requirements and from inspector familiarity with those techniques. Recently, Appendix VIII to ASME XI has been changed to require that all techniques and examiners be qualified on real cracks prior to being permitted to do inspections. Though the rules are not yet requirements, the qualifications are ongoing.

In requiring personnel and techniques to be qualified, Appendix VIII also allows any technique to be used as long as it can pass the requirements for successful demonstration. *FAST* UT was developed to take positive advantage of this “Code” change.

History of the FAST™ Technique

FAST began as an enhanced examination for thin walled piping welds due to difficulties in performing examinations with shear waves. “Code” required calibration reflectors for piping examinations are typically notches based on a percentage of wall thickness; the thinner the pipe, the more shallow the notch. The examination sensitivity is set off the reflection from the appropriate notch. Initially materials less than ½ inch in thickness were exempted from ultrasonic examination but as “Code” regulations became more stringent lesser pipe thicknesses were included. Shear wave examinations in this range of material thickness using the traditional pulse-echo methods found problems in sensitivity from the Fresnel zone. The gain required to bring the notch reflector to the

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examination levels established by the “Code” were high and caused extraneous signals making interpretations difficult. Due to these difficulties with the shear wave techniques and the need to comply with the regulators request alternative ultrasonic techniques were sought.

To avoid the effects of the Fresnold zone dual pitch/catch transducers were considered and to avoid extensive conditioning of the welds a high angle of 70 degrees was selected. The problem with root geometry causing extensive reflectors was still prevalent using the shear wave dual probes. In an effort to reduce the effects of the weld root geometry 70° L-waves were tried. Weld root and other reflections associated with non-flaw conditions were significantly reduced.

The transducer used consisted of a side by side dual with each element being ≈.30” high by .15” wide. The angle was 70° and the roof angle focus was set to ≈.30” of part depth. The exit point was put close to the front of the shoe to allow for access across the weld without the need for conditioning the crown. Amplitude was not a evaluation criteria with the L-wave technique signal position was. A demonstration of the technique to the regulators and “Code” inspector was performed and approved for use on a augmented basis. The concept is similar to using a straight beam, first the material thickness is established, the crt is then set to represent depth, the scan is then performed and signals that occur within the zone determined by the material thickness are evaluated as flaws.

When tried on thin wall piping with inside surface connected cracks, a very strong signal was seen. The ID geometry from the root bead was apparent but very small in amplitude. A different scanning technique was employed which eliminated those root indications from the inspection area. Hence, with careful positioning of the transducer and a planned scan pattern, the examination resulted in the cracks being the only indications seen. This made the examination fast and reliable.

The 70° L-waves worked so well on thin materials that the decision was made to see if the same concepts could be applied to thicker materials. Transducers were built which were larger in size and with the roof angle focus at various depths at around 1.0” of material. 70° angle L-waves were again tried.

Again the results were very encouraging. With proper positioning and the correct scanning technique, the only signals to evaluate were those of the cracks. All signals from geometric reflectors were of low amplitude and far enough out in time that they could be totally ignored. The transducer worked very well on materials up to 1 inch thick. However, at greater thicknesses there were other problems encountered.

The process continued and further attempts were made to develop the technique for thicker materials. After some experimentation a new transducer for the mid range thickness was designed and built. It remained a side by side dual

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element transducer at 70°. The roof angle focus on this model was closer to 2.0" in material depth. The element sizes were increased accordingly.

The results on the thicker materials were successful. Material depths of up to 3.75" were inspected easily and reliably. The only indications to evaluate were those of the cracks. Geometric signals were very low in amplitude and were eliminated from consideration by the technique.

In all size ranges, all ID connected flaws were clearly seen and easily identified as being cracks. No unrecognizable geometric signals appeared in the areas of concern. The deeper the flaws, the easier they were to detect.

Basics of the Flaw Analysis and Sizing Technique (*FASTÔ*)

This technique is a 70 degree high angle longitudinal wave ultrasonic examination technique. It relies on the fact that specular reflections from the longitudinal waves received from flaws will arrive in time before other reflections from internal surface features. Specular responses and signals found in the first leg occurring at depths greater than the wall thickness are not associated with internal flaws and can be ignored. Signals occurring at the wall thickness and less are the only signals requiring evaluation. The reduction in geometric reflections from the weld root and associated conditions are significant with the 70 degree longitudinal probes. This dramatically reduces the amount of signal evaluations in the inspection area. To reduce the effects of the ever present 33 degree shear in the 70 degree longitudinal wave probe the use of lateral scanning from a fixed position and specialized longitudinal probes has been established.

The scanning pattern utilizes a select portion of the sound beam projected by the transducer to get maximum coverage per scan or sweep. More than one scan line may be used to assure coverage of the area of interest. The broad impingement of the sound beam on the inside surface covers the root area plus a large volume of the weld in one sweep. By modifying the transducer size and using all aspects of the projected sound beam some welds can be inspected in one scan. Flaws can be length sized and characterized from this initial scan.

Calibration of the 70 degree longitudinal wave transducers is a depth calibration performed on side drilled hole .031 inches in diameter spaced at tenth inch intervals of equivalent material depth. Since, longitudinal waves have long echo-dynamic patterns the calibration is performed from fixed positions. This is done by using the known surface distance of the 70 degree probe and placing the exit point over that position while setting the sweep to the appropriate screen division for the hole depth being established. Peak amplitude is not used only sweep position information. The calibration of the sweep using a

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fixed probe position is always plotted as a 70 degree angle. The amplitude of a signal is not an indicator of a flaw it's relative position is.

Examination sensitivity is established by two methods, one is by using the side drilled hole of equivalent depth and setting the gain for a 50% screen height signal or the option is to scan laterally while adjusting the gain for a 5-10% roll from the inside surface. These settings provide sufficient gain for locating all types of defects. Once a defect is located the through wall sizing steps can be performed.

As detection procedures were being developed for each size range, through wall sizing was also being evaluated. Throughout the examination of thinner materials, tip diffracted signals were readily apparent when planar flaws were present. In most cases, for flaws greater than .1" in through wall extent, it was very easy to see the tip diffracted signal. In those cases where the tip signal was difficult to see, the flaw depth could be closely estimated from the echodynamics of the indication.

With *FASTÔ*, there is a pattern of collateral echoes present when ID connected flaws are detected. In addition to tip recognition, attempts were made to estimate flaw depths based upon the spacing of the collateral echoes and other relationships seen with those echoes. This did seem to work. However, it was determined that using the information from the collateral echoes was an unnecessary application.

The most accurate way to determine the depth of a flaw is from the tip diffracted pulse. If that signal can be reliably identified and its position determined, then the flaw depth can be determined. With *FASTÔ*, this process is straight forward and simple.

The L-wave signal provides a continuous signal from flaw base to flaw tip as the sound beam is moved from the inside surface intersect position to the flaw tip position. Once the tip has been passed by the beam then a signal amplitude drop occurs. Just before this point, the tip signal is usually readily apparent. If the tip signal is not apparent, then a very close estimate is possible due to the characteristics of the indication as the beam passes over the flaw tip.

It was determined that the easiest method for flaw tip detection was to work with the L-wave signal. Disregarding the other signals made the task much simpler and as a result there are fewer mistakes made due to misidentifying flaw tips. Additionally, flaws which are not perpendicular to the scan surface can be accurately sized.

The only difficulty with the sizing technique is with the very shallow flaws in the thickest materials. Once the remaining ligament over the flaw tip is over 2 inches, then the distance back to detect the flaw tip required by the 70° angle does make the flaw tip more difficult to isolate. For those cases, estimation due to echodynamics works well. Also, adjusting the range to "zoom" the flaw signal has proved useful in isolating the tip.

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First Use of the Technique

Once the technique was working consistently well on the specimens available it was then subjected to a Performance Demonstration Initiative (PDI) qualification examination at the Electric Power Research Institute (EPRI) NDE Center in Charlotte, North Carolina. The detection and through wall sizing qualification demonstration was successful.

Though the technique was successfully tested, there was difficulty. The high noise levels in some of the materials and the amount of geometric reflectors were problems which needed to be overcome.

FAST™ Transducer Development for IGSCC Detection

The prototype transducers had a resultant sound beam with a great deal of beam spread. It was thought that if the vertical height of the beam could be minimized and the energy concentrated on the suspect zone, then the crack signals from the IGSCC would be enhanced and the number of, and amplitudes of geometric reflectors would be minimized. SPIN worked with Krautkramer Branson to develop the FAST Model transducers.

The new transducers are unique from other longitudinal wave probes. The elements are made from a new composite material. This material is somewhat flexible allowing for bending of the elements providing different beam profiles that can be experimented with on flaws for detection and sizing results. The piezocomposite elements provided more energy than other elements of similar size. Material noise was reduced and the resolution higher. The beam shaping provided a design which allowed the vertical height of the beam to be contained. This intensified the longitudinal wave while de-intensifying the direct shear. The net effect was better tip signal response while reducing the shear wave reflections from inside surface geometries. The transducer while one of the least expensive components in an ultrasonic system is the lens of the eye in ultrasonic examinations.

The signals from these transducers is only about one and one-half cycles. This very high resolution makes tip sizing easier than it had been. The angle stays relatively true throughout the thickness range making it much more reliable for plotting indications.

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The Benefits of the New Transducers to the FAST Technique

Subsequent attempts through PDI with the enhanced technique and the new transducers provided excellent results. It was now possible to inspect all samples in a set with scan access limited to a single side even if the samples were austenitic and the set included IGSCC. This was done by 2 individuals using the new transducers as soon as they were delivered. In fact, both individuals inspected all the assigned specimens, approximately 15 each, in less than 6 hours compared to the 40 hours the examination normally takes.. Also, through wall sizing with the new transducers proved to be more reliable than the prototypes had been.

Benefits of FAST™

- ◆ Broad Range of Applicability
 - Same procedure including calibration, technique and equipment for
 - ⇒ Carbon steels
 - ⇒ Stainless steels (including IGSCC)
 - ⇒ Inconel
 - ⇒ Clad carbon steel
 - ⇒ Detection
 - ⇒ Length sizing
 - ⇒ Through wall sizing
 - From scan surface also
 - ⇒ Material thickness from 0.1” through 4.0”
 - ⇒ Curvatures from 2.00”diameter to flat plate
 - Curvatures down to 0.75”diameter with new FAST-SD transducer
- ◆ Increased reliability for characterization of indications.
 - Geometric indications are substantially reduced or eliminated
 - ⇒ False calls are substantially reduced
 - Only indications at predetermined time of flight need be considered
 - Flaw indications are confirmed by:
 - ⇒ Location
 - ⇒ Appearance
 - ⇒ Echodynamics
 - ⇒ Not dependent upon amplitude
 - Increased penetration of noisy materials with L-waves
- ◆ Most reliable method available for detection of deep flaws
 - Long echodynamics

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- Increasing amplitude as transducer gets closer to flaw
- ◆ Most reliable method available for detection of axial flaws
 - Multiple modes of propagation increases detection capability
- ◆ Most reliable method for through wall sizing of ID and OD connected flaws
 - Tip diffracted signals are:
 - ⇒ Easily located
 - ⇒ Easy to recognize
 - ⇒ Have good signal to noise
 - ⇒ Have good resolution
 - When tip diffracted signals are not readily discernible, then flaw height estimation is possible based upon echodynamics
 - Sizing is not dependent on flaw orientation
- ◆ Sizing of flaws connected to scanning surface
 - No “skip” off of ID required
 - Depth sizing technique for indications found with surface NDE methods
- ◆ Reduced Equipment Required
 - All calibrations done with same calibration block of same material
 - ⇒ Carbon steel and clad carbon steel
 - ⇒ Stainless steel
 - ⇒ Inconel
 - ⇒ Any similar material
 - Calibrations for all pipe sizes done with same calibration block
 - Same calibration block for detection and sizing
 - Same transducer for detection and sizing
 - ⇒ Entire range of thickness covered with 3 transducers total
 - ⇒ Thickness range is from 0.1” through 4.0”
- ◆ Reduced Examination Time
 - Single scan to cover entire weld
 - Sizing done at same time as detection
 - ⇒ No additional calibrations
 - ⇒ No additional techniques or scans
 - Reduced data to record as only flaws produce recordable indications
 - ⇒ “Peaking” of indications is not required for recording
 - Reduced time to analyze data
 - ⇒ Flaw indications are easily confirmed
 - ⇒ Characterization of flaws done with no additional steps
 - Reduced paperwork
 - ⇒ Fewer calibrations
 - ⇒ No data to record unless its a true flaw

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Comparison of Techniques

At the request of several nuclear utility companies, EPRI conducted a comparison of FAST (NU-LW-1) and conventional techniques. The comparison is of data from all those people who have participated in the PDI qualification examinations. The data compared is between all examiners on both techniques. The data includes results from both passed and failed tests. The data includes only flaws where scan access from both sides of the weld was provided. The only comparisons shown here are for detection.

The final report has been issued. Some of the data which was presented has been reformatted below to show how FAST compares to the conventional techniques. The comparisons are between detection categories on various materials, pipe sizes, and flaw mechanisms.

In every category compared, FAST showed a higher rate of accuracy when the amount of detections versus false calls are considered. The following numbers are taken from the EPRI report.

FAST™ detection / false call rate	Conventional detection/ false call rate	Comments
81 / 8	83 / 18	all austenitic categories
96/ 8	97 /15	all ferritic categories
89/ 5	89/17	<0.5” Thickness - all materials and flaw types
77/ 10	81 / 19	>0.5”to 1.5” Thickness - all materials and flaw types
89 / 5	93/ 13	>1.5” Thickness - all materials and flaw types
89 / 8	87 / 15	>0.5”to 1.5” Thickness - all materials with No IGSCC
53 /14	67 / 30	IGSCC only

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This table clearly shows that FAST is more accurate at determining flawed material from unflawed material. Even in the IGSCC category, the only category where the detection rate for FAST is significantly lower than with conventional techniques, the percentage of correct calls minus false calls still exceeds the conventional methods.

Other facts that come out in the EPRI report are:

- * depth sizing results are at least equivalent
- * length sizing results are approximately the same
- * FAST is at least 25% faster during the qualification testing
- * 80% detection of all axial flaws vs. 64% with conventional
- * 100% detection of all flaws over 60% through wall depth

The effectiveness of any procedure should be based upon the accuracy of classifying the significant conditions without misclassifying nonrelevant conditions.

False calls can be expensive. The time that it takes to resolve suspect indications is expensive. Unnecessary repairs and unnecessary downtime can result from procedures which do not accurately classify indications.

Conclusion

FAST™ UT has been proven by demonstrations to be a simple, efficient and reliable technique for detection and sizing of planar flaws. The technique is in use today in a few nuclear plants in the US for ASME XI required inservice examinations.

The technique is revolutionary in its versatility and simplicity. It is easy to learn. It is versatile in that detection, sizing, and characterization, are all done with the same technique and the same equipment. Several different materials can be inspected with the same equipment and calibrations. The technique has been shown to be effective to depth size indications found with liquid penetrant and magnetic particle testing.

Future developments will be in the area of weld flaw detection and classification. Most of the development to date has been for inservice cracking. It is excellent for weld flaw detection as well, but there are few codes which will permit it as a stand alone technique. *FASTÔ* is still too new for codes to recognize it. Work is underway to proceduralize the detection, characterization, and sizing of weld flaws.

The automation of this technique has been funded by PRCI and AGA for pipeline production work. Proof in concept testing has been completed and work is underway to produce portable reliable ultrasonic imaging systems capable of using the *FASTÔ* technique.