Ultrasonics as a Detection Tool

Mid-wall creep fissuring in cast HK40 reformer furnace tubing can be detected using ultrasonics and specialized techniques.

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One method employed in ultrasonic inspection is based on the "through transmission" technique. This method requires the use of two crystals. These crystals are aligned geometrically so that the energy transmitted from one energizes the other. The data is interpreted on the overall energy, or lack of energy, reaching the receiver. The discussions in this paper will be limited to this through transmission technique.

Water is a good conductor of ultrasound and can be used to transmit the sound produced by the crystal to the material under test. Assume that a steel part is immersed in a tank of water. When two crystals are positioned on opposite sides of the part and the transmitter is properly energized, bursts of sound waves are transmitted from the crystal. This pulse travels through the water and in a few microseconds reaches the part. When the pulse reaches this water-metal interface, a point which cônstitutes a mismatch of acoustic impedance, part of the pulse is reflected back and the rest of the pulse continues on through the metal. This impedance mismatch is the determining factor which controls the quantity of sound that is reflected from this interface. In a water steel interface approximately 90% of the sound is reflected. At this point, where the pulse is reflected back through the water to the transducer, another pulse is continuing into the metal part. Thus, the pulse energy is split into two portions, each traveling in opposite directions along the same axis.

Test unit in operation in a furnace.

As the pulse traveling through the part reaches the other side, the pulse is again split due to an impedance mismatch. In a steel-water interface approximately 10% of the sound is reflected. At this point the pulse is reflected back to the crystal, another pulse is continuing into the water. This pulse traveling in the water will arrive at the receiver crystal, if the crystals are properly aligned. This transmitted pulse which arrives at the receiver crystal is displayed on the cathode ray tube as a vertical deflection, Figure 1.

The amplitude of this vertical deflection is proportional to the amount of sound which is transmitted through the metal, any reflector in the metal would cause the sound not to continue through the part and would reduce the amplitude of the received signal or the vertical deflection. Other factors which could cause a reduction in the received signal are poor ultrasonic couplant, and other attenuation factors in the material under test, such as large grain size.

When a sound beam passes through two materials with

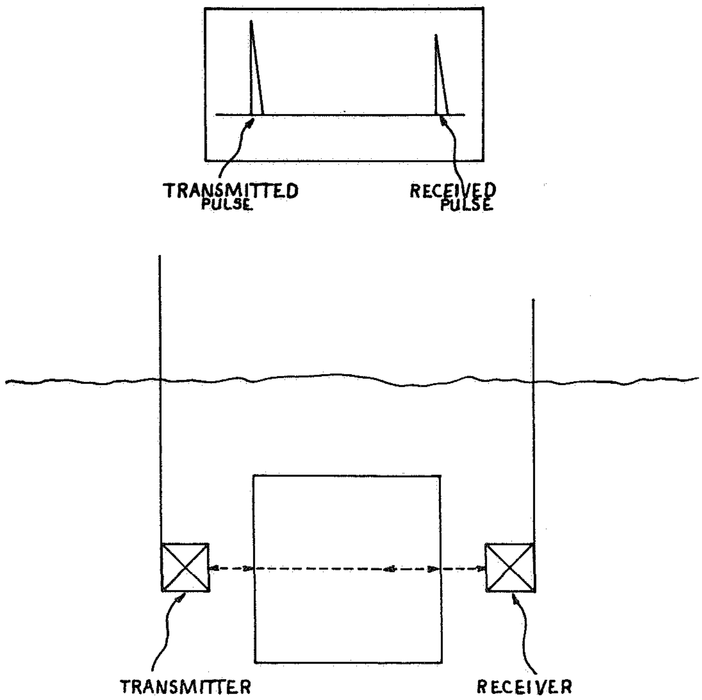

Figure 1. The transmitted pulse is displayed as a vertical deflection.

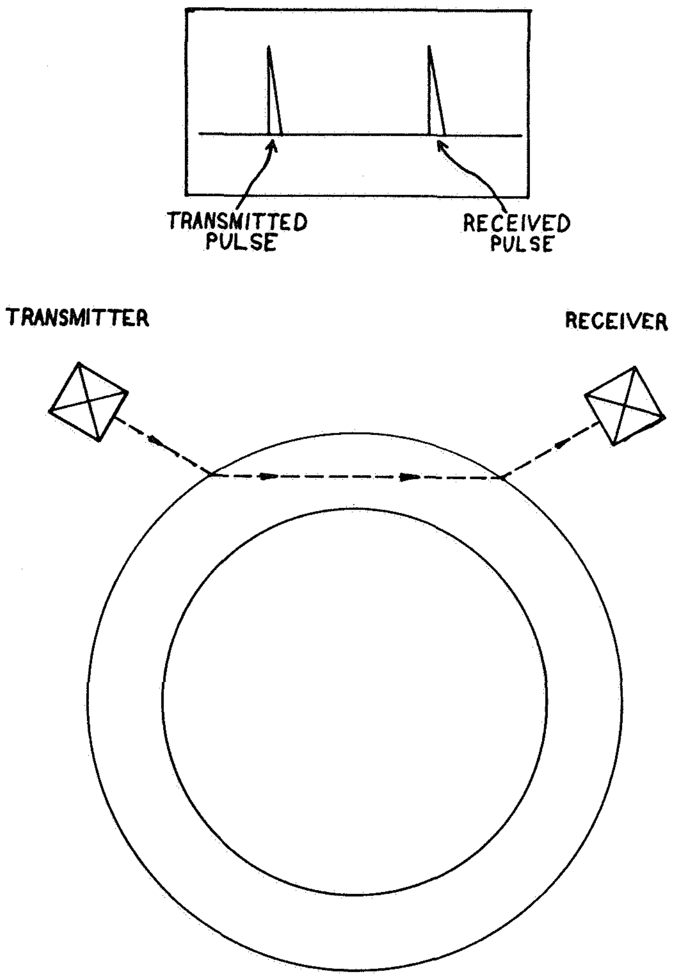

Figure 2. Sound could be transmitted through materials to another crystal.

different sound velocities the sound beam is refracted at the interface. This refraction can be computed by Snells Law.

$$\frac{SIN\ \Theta_1}{V1} = \frac{SIN\ \Theta_2}{V2}$$

Where
Θ_1 = Incident Angle
Θ_2 = Refracted Angle
V1 = Velocity in First Material
V2 = Velocity in Second Material

By using Snell's Law and computing the proper incident angle, sound can be transmitted through materials at some refracted angle to another crystal which is receiving sound at the same angle of incidence, Figure 2. The received signal is displayed on the CRT of the ultrasonic instrument. By using a gate which has an analog output the height of the received signal can be monitored using a strip chart recorder.

The development work

First tests were made in an immersion tank where the tubes could be immersed and various frequencies and refracted angles could be used in detecting the mid-wall creep fissures. Preliminary studies using low frequencies and through transmision seemed to give the best results on all samples which were available. "C" Scan recordings were used as the recording method for the first evaluation tests. Although, the results were very good in the laboratory immersion tank, field evaluation of the method was needed.

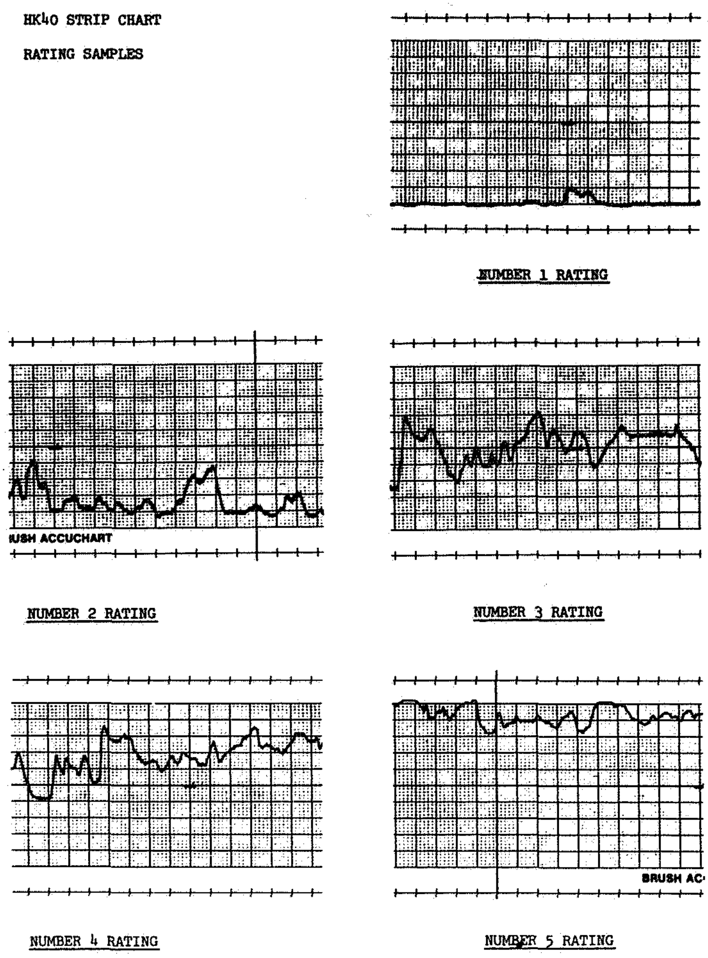

Figure 3. Results are evaluated on a grading level, 1 thru 5.

This was accomplished using a mock-up of the proposed inspection unit and the results proved to be as good as the results obtained in the immersion tank.

A production tool was built which would provide reliable results, in as short a time as possible for inspection. This tool was built to examine 17 in. of tube on each scan. 17 in. was used in order to compare results with the radiography which had been done in the past. Several furnaces were examined using the above tool and the results were good. However, sandblasting the tubes in the inspection area increased the sensitivity and repeatability of the test.

Because sandblasting the tubing is costly, difficult to perform and clean up, continued research was employed to refine the inspection method to eliminate the necessity for the sandblasing. By optimizing the sound beam angle and some equipment and search unit modifications, tube samples were inspected without the sandblasting operation and no significant decrease in sensitivity or repeatability was noted.

During this same time period interest was given by several firms, to increase the scanning operation to cover the complete tube length and inspect both fired sides of the tubes at the same time. This equipment is now available and has been tested on sample tubes in the laboratory. Again, the results have been good. By using this inspection system no scaffolding is required in the furnace which further reduces the inspection cost to the operator. However, some tubes are warped and too close together and cannot be inspected full length unless the scans are made in short intervals.

Making the calibrations

Initial calibration is best made on known non-fissured and fissured tube samples. If no samples are available calibration can be made using tubes which are to be inspected, however, radiography must be used to establish final calibration levels.

Results are evaluated on a grading level 1 thru 5. A number 1 tube reports good sound transmissions through a non-fissured tube and a number 5 tube reports poor sound transmission through a severely fissured tube. Numbers between 1 & 5 represent intermediate degrees of fissuring, Figure 3.

Ultrasonics have proven to be a reliable method for the detection of mid-wall creep fissuring in cast HK40 reformed tubing. Continuing development is being made in the method to increase the ability to separate various degrees of fissuirng in order to allow operators to predict tube life and plan future tube replacements and shutdowns. Inspection is very rapid and no catalyst need be removed in order for the inspection to be performed. #

MARLOW, R. E.

DISCUSSION

Q. I'd like to know how long it would take you to check an entire tube on your full length scan, and I'd also like to know what the effect is at the weld on the tube?

MARLOW: As far as the full length scan, you're talking about around 40 feet? We have not done a furnace full length, and I wish we had, but we haven't at this time. It looks like around 10 to 15 minutes for a full scan of 40 feet. That's after you're set up on the tube. I'm just trying to give you a feel now for 10 to 15 minutes on a full 40 length inch—40 foot scan. (NOTE: Full length scans 40 ft. tubes take about 9 minutes each including set up.)

Now as far as the welds go, we haven't had any success at all doing anything on the welds. And all we're doing is getting over them, and basically we don't look at anything in the welds at all. I guess because nobody's asked us to try to do anything on the welds, at least specifically. And I think it would be a very difficult problem ultrasonically to try to evaluate anything on the welds.

GEORGE KERNS, Du Pont Co.: I'd like to interject a note here regarding the metallurgical condition of these tubes. You made the point that you could not readily distinguish between fine fissures and very large fissures in the tube using ultrasonics, and that subsequent radiography doesn't detect fine fissures.

Well, I think so far in the work that's been done regarding residual life of tubes, which I think all of us here are interested in, there has been no definitive study to determine a difference in remaining life for a tube with a few large fissures, as opposed to one with many small fissures. In essence, we're dealing with the same parameters in both ultrasonics and creep damage, i.e., the area fraction of creep voids in the plane normal to both the hoop stress and ultrasonic wave path. Thus, there may well be a correlation between many fine fissures and a few large fissures as being equivalent in terms of both remaining life and ultrasonic attenuation.

I think it is important in any materials testing program to try to answer this question regarding the effects of size and distribution of creep fissures in aged material, as affecting the remaining service life of the tube. A few stress rupture tests could provide this answer.

We're attempting to do this at Du Pont, though I think it's a question that's really got to be answered in order to attach some significance to the ultrasonic test results for tubes which are well into third-stage creep.

MARLOW: We found the people we have dealt with so far have agreed with George that at this point, they really don't know whether a multitude of fine fissuring is any better per se than one or two large gross fissures.

Q. You indicated that the scan time of a 40 foot tube would be about 15 minutes. What would you estimate would be the set up time between the tubes which would also be added to the 15 minutes? Also, a second question. In your paper, you indicate that initial calibration is required? Is this on each furnace, is the calibration required? And then, as you say, if no samples are available, radiography must be done to establish the criteria? Can the radiograph be done with the catalyst in place, or must it be removed?

MARLOW: First off, set up time is after you're once in the furnace, and you're not moving tremendous distances, something like two to three minutes. And it is not a big thing. It should be about that.

Again, these are all estimates. We have not tested any furnaces full length. If you ask me at the end of next month, I'll let you know, because we have some contracts for next month where we're going to be inspecting full length tubes.

Calibration is required, and that's the tough job. In order to set your scanning levels, we found that in most cases we would like to get tubes out of the furnace if there's a possibility, to use as calibrators. We have, for most of the furnaces we have tested right now, sample tubes all set up. We have tubes like the tube you saw the slide of with fissured and non-fissured areas to use as calibration standards. It's a very good calibration standard because you can set up on it very easily. We are working these up on all furnaces we can get tubes from which have fissured and non-fissured areas. Unfortunately some of the furnaces we have nothing on, and the tubes are so much different in size that other calibration standards will not work. This is something that amazed me when we got into this field, that so far we haven't found two furnaces with the same size tubes.

I don't know whether this was intentional or what the scheme is, but this is especially annoying to us because we have to build special shoes for every size furnace tube, every diameter and every wall thickness. So every time somebody calls us for an inspection, we have to build another shoe. Sooner or later we're going to find somebody that has another tube the same size, but until that time comes, when we go in and start testing in a furnace, we attempt to set our calibration at some level on some particular tube that we're inspecting so that we can come back to that tube and know where we're at, at least as a feel for some continuing calibration.

And then as soon as we find some tubes which seem to show indications of some loss of sound, we like to radiograph if we can. Now, obviously the fissures have to be pretty bad in order to be seen with the catalyst in the tubes. If the catalyst is out, it helps the situation alot. If the catalyst is in, we try to look at the worst tube we can and get the best radiograph possible to see if we can correlate our loss of sound. Calibration is a problem and we have to work with the furnace people on that to come up with some suitable level.

Usually we run as low as possible in sensitivity, so as not to make the tubes all look bad but not to make them all look good. So we have some variation there we can use to evaluate the tubes, if we don't have a calibration standard.