AMAS Workshop on Nondestructive Testing of Materials
NTM'03 – (pp.53–75) – Warsaw, May 19-21, 2003.

The Center for NDE at Iowa State University and industrial inspection interactions of the Iowa Demonstration Laboratory

D. UTRATA

Center for Nondestructive Evaluation
Iowa State University
Ames, USA
heydave@cnde.iastate.edu

1. Introduction

The Center for NDE (CNDE) at Iowa State University in Ames, Iowa, is one of the preeminent research centers in the world in the area of nondestructive evaluation. A number of principal investigators, assisted by graduate students from the University, develop science and technology in areas such as ultrasonic inspection, eddy current inspection and radiography.

One major program within the CNDE is the NSF – Industry/University Cooperative Research Program, sponsored jointly by industrial companies, the National Science Foundation and Iowa State University. Founded in 1985 with 14 industrial sponsors, the program now includes more than 20 member companies who pay a membership fee each year. The research is directed toward areas of industrial interest while maintaining compatibility with academic requirements for student participation in degree programs. The IUCRC emphasis is in the fields of aviation, transportation, energy, and manufacturing.

The Iowa demonstration Laboratory (IDL) was formed in 1992 as an outreach arm of CNDE. It was developed to permit state-of-the-arts research to be available to smaller industries, primarily within the State of Iowa. Beyond the application of research knowledge to assist small- to mid-size manufacturers, the program's goal is to help manufacturers to become educated consumers of nondestructive testing services and/or products. Within this task, the IDL does not compete with commercial sources, as the program's funding coming from the state government.

2. Experience in industrial interaction

Working in outreach for over a decade, the IDL has gained a range of experience with various manufacturers and industries. The comments in this paper are intended to give a flavor of the variety of these interactions. The information and suggestions ventured in this paper are not intended to strictly guide an engineer or practitioner of nondestructive inspection in dealing with industry. Rather, the experiences documented here are submitted to those within the nondestructive evaluation community as possible guideposts to assist in dealing with manufacturing professionals not acquainted with inspection principles and background.

An important aspect to keep in mind when discussing nondestructive inspection protocol and advantages with manufacturers is that often the personnel involved in the discussion will have little or no direct experience with NDT, and may have only superficial knowledge of the principles behind the inspection. Critical discussions aimed at assisting the organization to implement nondestructive inspection practice would then entail providing: a solid understanding of the science behind the technique, an appreciation of the engineering required to implement the solution in the manufacturing environment, and the need to fully understand the cost of the current problem, or doing without the inspection. It must be remembered that, regrettably, nondestructive inspection is often viewed as a necessary evil that should perhaps be undertaken in manufacturing, yet is seldom appreciated.

In the course of industrial interactions in which the IDL has participated, it has been seen that different companies exhibit different learning curves when implementing specific nondestructive testing practices. Mistakes are made as new hardware or techniques are explored. Such mistakes are generated from both low- and high-tech concerns. The case histories that will be generalized in this paper are intended to display the range of problems encountered. It is hoped that a discussion of what can go wrong in the application of nondestructive inspections will serve as an indication of areas the practitioner/researcher should focus upon as they work with manufacturers.

3. Case histories for various techniques

Three nondestructive inspection areas were chosen to illustrate some of the lessons learned by the IDL via industrial interaction with different manufacturers. They represent a long-used inspection method, magnetic particle testing; a technique that has enjoyed significant technological advances in recent years, ultrasonic testing; and a technique that seems to require vastly different responses depending on its application, leak testing.

3.1. Magnetic particle testing

Magnetic particle testing is routinely used for the detection of surface and near-surface discontinuities in ferromagnetic components. This NDE method utilizes a magnetic field introduced into a ferromagnetic material, and subsequent application of iron particles (either dry or suspended in liquid) to provide a visual indication of a flaw. This method is employed in numerous industries, from small to large shops. Its long-term usage, however, could be interpreted as having led to some problems in its use.

Arguably, this method has not been associated with deep-rooted, quantitative improvements, as have other methods. Having been used for a number of years, a manufacturing perspective of this technique might be that improvements have been made in the electrical components within magnetic particle test stands, but the inspection itself has changed little over the years. Of course, this perspective is not accurate. Numerous refinements in the test hardware, inspection particle makeup and visualization aids such as ultraviolet light quality, have gone on for some time and continue to this day.

Nonetheless, many users of the inspection perceive the technique as stagnant. This assessment of magnetic particle inspection as a rather mundane test has perhaps come about due to the apparent simplicity of the equipment used in this test. This perception may also lie in relying ultimately on a simple visual interpretation of the data. In any case, possible missteps in applying this technique can be readily overlooked in inspection shops if proper guidelines are not in place.

A problem area that has been witnessed firsthand by the IDL is when this inspection is performed "the way it's always been done" without a periodic evaluation of in-house test and training protocol. Lacking a reappraisal of the inspection procedures, failures of the inspection process may not be detected. Situations that have been noted in visits to manufacturers who perform this inspection without critically evaluating their process include:

- not optimizing the inspection of a particular part, such as testing a gear in a head-shot configuration as opposed to using a central conductor,
- using a contaminated bath that has deteriorated with use,
- performing the inspection in an area not sufficiently shielded from ambient light (for fluorescent magnetic particle inspection) or using an ultraviolet lamp that has inadequate intensity,
- inspections performed on a variety of components by inspectors who overlook the distinction between head shots and coil shots,
- leaning a copper central conductor rod against a tail stock during a head shot, *for absolutely no benefit or merit,* other than "that's the way it's always been done".

Admittedly, these concerns can border on the simplistic, especially the two final ones. However, the fact that such errors can creep into service indicates the potential exists for other problems that may require closer scrutiny. The concerns identified in this short list are indicative of issues that arise from low-tech aspects of the inspection process. Concerns that are more state-of-the-art, or high-tech, include questions that arise which are often beyond the experience of conventional usage.

An issue that is currently undergoing critical review is the nature by which the electric current in magnetic particle machines is produced. Specifically, inspection equipment often allows for the user to choose between AC (alternating current) and DC (direct current) to be used for testing. It is generally accepted that the use of AC excitation focuses on the detection of surface-breaking cracks, while DC is used to promote the detection of near subsurface indications. The choice between these two modes is usually a clear option for the test operator: a simple AC/DC selection switch. However, the means by which the "DC" magnetization is created is not at all obvious to the operator.

The use of "DC" magnetization really implies that that alternating current is rectified, such that an effective direct current is produced. Depending on the equipment used, including its source and vintage, this condition may be attained using single- or three-phase rectification. As noted, this distinction is quite transparent to the user of the technique. While the ramifications of using one system over the other may not affect standard operating procedures for the inspection of certain components, it can be seen that instances occur when a certain level of sensitivity is expected or required.

This issue of the method of rectification in magnetic particle testing has been raised in the inspection of critical aerospace components, and is highlighted by some results made available to the IDL. In this instance, comparative tests using a Ketos ring indicate the concern. Briefly, a Ketos ring, shown in Fig. 1 and shown as used in conjunction with a central conductor in Fig. 2, demonstrates the sensitivity of a given piece of equipment and/or test procedure to detect subsurface defects. Electrical current flowing along the conductor creates a magnetic field in the Ketos ring oriented in the radial direction. At progressively deeper holes in this test piece, magnetic flux will leak out of the piece to a lessening degree, creating ever fainter magnetic particle indications. The flux density leakage that occurs at these holes during magnetization can be visualized using finite element modeling, as shown in Fig. 3[1]. Different means of rectification can be applied to the electrical

---

[1] Image from article in Materials Evaluation, July 2000, used by kind permission of Vector Fields, Inc., Aurora, IL, USA.

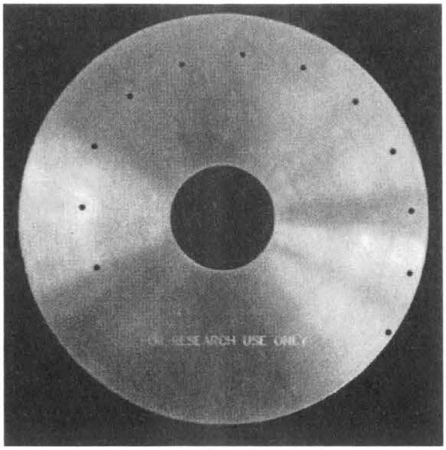

FIGURE 1. A Ketos ring, used in magnetic particle testing to reveal the ability of hardware or protocol to detect subsurface discontinuities. These discontinuities cause linear indications to form on the outer edge of the ring during inspection.

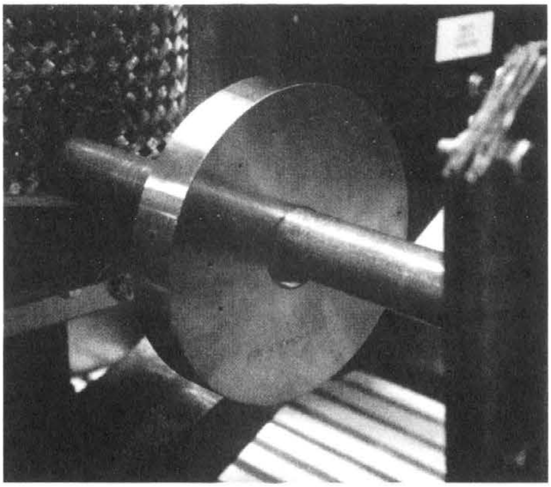

FIGURE 2. A Ketos ring mounted on a central copper conductor rod. Passing magnetization through the rod creates radial magnetization in the ring.

current for "DC" magnetization. The effect of this is shown graphically in Fig. 4, showing results from an experiment using a Hall probe positioned over the first three holes in a Ketos ring during magnetization[2].

---

[2] From experiments performed at Magnaflux, Manchester, IA, USA – given to author in private communication.

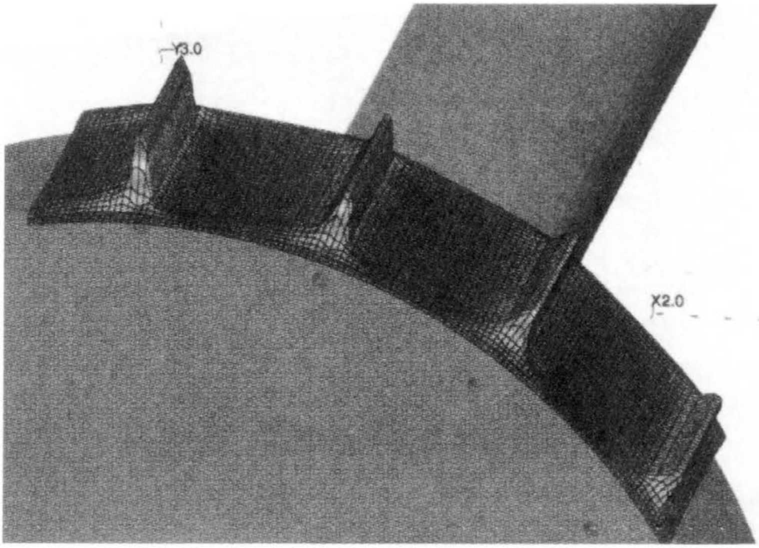

FIGURE 3. Surface map of flux density showing typical patterns in a Ketos ring test. The pseudo-color mapping indicates reduced flux density at the surface above deeper holes. (Image reproduced by kind permission of Vector Fields, Inc.)

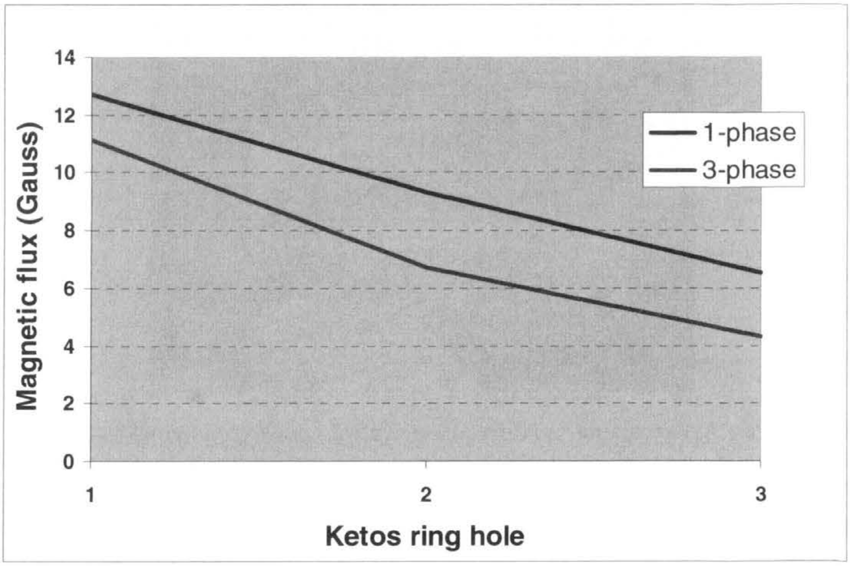

FIGURE 4. Graphic representation of flux leakage measured above the first three holes in a Ketos ring as it was tested during single- and three-phase "DC" rectification of the electrical current.

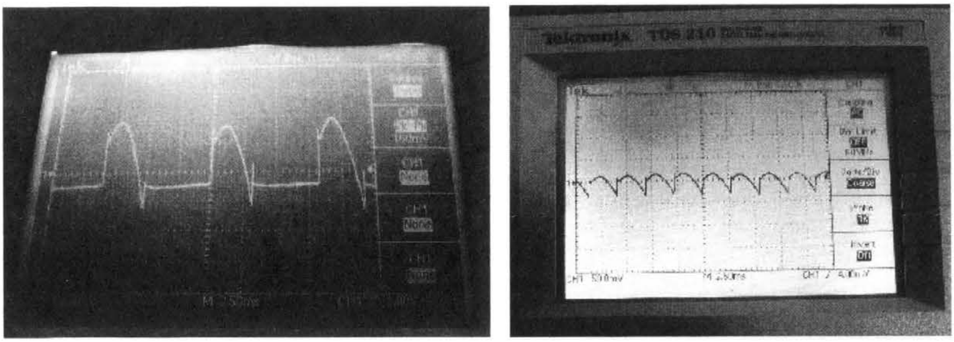

FIGURE 5. Oscilloscope captures of the "DC" excitation waveforms on single-phase rectification magnetic particle units (left) and on three-phase rectification units (right). The nature of these waveforms can quantitatively affect the outcome of the inspection process. (Photos courtesy of Magnaflux)

The electrical current can be rectified in single- or three-phase modes, dependent on the nature of the hardware in the magnetic particle unit. This is usually a completely transparent mechanism to the operator, who would simply access an AC/DC switch on the machine. The waveforms of the excitation current in units operating with single- or three-phase rectification are shown in Fig. 5. While there is clearly a difference in the characteristics of the waveforms, the more insidious concern is that this difference could lead to ambiguous or unclear flaw determination.

As seen in the plot in Fig. 4, the flux density over subsurface defects will be different depending on the means of electrical current rectification. The results of following a particular inspection in "DC" mode, wherein amperage and time of electrical current are the parameters specified, could therefore lead to inaccurate conclusions. Specifically, the data supplied to the author regarding the equipment comparisons shown here can lead to detecting the fourth hole in a Ketos ring or not. This could conceivably lead to a testing facility's inability to qualify their inspection with the cause of the shortcoming not readily identified.

Another area in which concerns over such subtleties as the method of rectification of the magnetizing current will likely have an effect is in forensic serial number recovery. In this practice, a ferromagnetic item that has had identifying marks filed away can be submitted to number recovery. When such serial numbers are stamped onto an item, the residual deformation under the stamp can often be coaxed into producing a magnetic particle indication. This is an area of law enforcement forensics concern that is parallel to the detection of subsurface anomalies in quality inspection.

Clearly, if the method of rectification in magnetic particle inspection can have quantitative effects on Ketos rings, it will also have an effect on the ability of crime labs to recover obliterated serial numbers of firearms. This is an area of work that is currently being investigated at Iowa State University and Ames Laboratory under the guidance of the Midwest Forensic Resource Center, in which the author is an investigator.

3.2. Ultrasonic inspection

Ultrasonic inspection uses the transmission of high-frequency sound waves into a material to detect imperfections or to locate changes in material properties. The most commonly used ultrasonic testing technique is pulse echo, wherein sound is introduced into a test object and reflections are returned to a receiver from internal imperfections or from the part's geometrical surfaces. The ultrasound can be introduced into the component by direct contact, using a gel couplant and a handheld transducer, or by immersing the part in a tank of water and using a computer controller to generate "images" of the internal structure of the component. A technique that is gaining in popularity and finding more widespread application is air-coupled, through-transmission ultrasonic testing.

The IDL has worked with a number of industrial clients to evaluate the utility of this inspection practice for their production. The variety of applications ranged from the inspection of raw material for cleanliness prior to machining to the qualification of manufactured goods prior to the sale to customers. In many instances, the guidelines to determine the inspection criteria were not based on a cited specification, but rather the desire to inspect something to see if it was "good." In this instance, often the most useful sequence of events was to demonstrate the ability to examine the part to a high degree, correlate this with easier methods to employ on the shop floor, and demonstrate that this method could alleviate, or at least reduce, the need for destructive testing. In all of this work, the underlying emphasis has always become the development of an inspection protocol that is cost effective to the company and yet does not demand a high level of interpretation from test personnel.

A thorough inspection of a part is typically done utilizing computer controlled C-scan data, even if it is deemed early in discussion with the industrial client that such scanning will not be practical in their shop environment. The purpose is to provide investigators in the IDL with as much knowledge of the part as possible, beyond the "good/medium/bad" classification that manufacturers will likely be able to submit for analysis. In most cases, a referee set of graded samples is not available for study, and a full inspection is required to screen material to find extreme product conditions for further study.

One such application was the inspection of steel bar stock that was to be machined into hydraulic manifolds for aerial lift equipment. Such manifolds can be subjected to over 21 MPa (3000 psi) in oil pressure in service, and it is critical for these parts to not leak due to internal defects such as delaminations or high levels of centerline segregation. The manufacturer tests such parts prior to sending them out into service, but there is still a significant delay time and monetary cost associated with machined parts that are later found to be inadequate. The IDL performed a preliminary inspection of incoming bar stock, and identified regions that produced relatively more indications than others. This was the initial step in identifying a useful criterion that the company would find useful for its product and be able to implement without established cleanliness standards as references. Samples of the bars were then examined using an immersion system, and pseudo-color images of the material's internal structure were obtained, with a typical sample shown in Fig. 6.

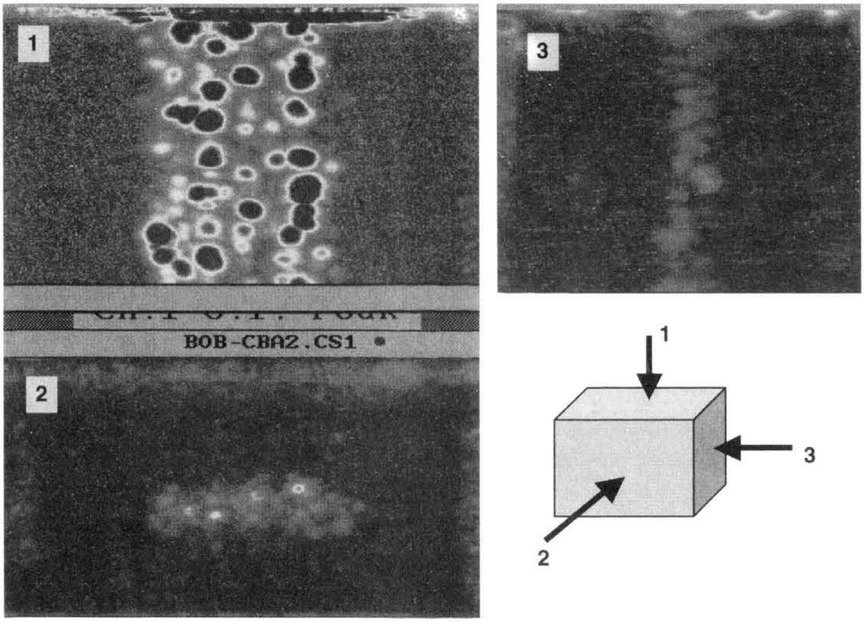

FIGURE 6. Ultrasonic C-scan pseudo-color maps of a typical bar sample exhibiting significant indications. The patterns obtained by inspection through the orthogonal faces of the block clearly suggest a centerline segregation/delamination region associated with the steel's initial fabrication.

As can be seen in this set of images, the indications on samples obtained from the manufacturer suggested that a defect associated with the initial rolling fabrication of the material was the culprit to be detected. The C-scan data was obtained by adjusting reflections from the central indications to go somewhat off screen on the detection system oscilloscope, allowing the overall backwall reflection to register slightly above noise on the screen. Once the general shape of the likely defects was identified in rough scans, it was evident that the corners of these blocks would yield essentially clear signals.

The next step in the investigation was to transfer a suitable version of this scanning capability so that manual inspection could be performed using a handheld contact transducer and monitoring A-scans on a flaw detector. Some engineering or production personnel often see this transfer as counterproductive. It was stated, for example, that "pictures" of the sample (C-scan images) are great, but "wiggles" on a screen (A-scan signals on flaw detectors) are worthless. Obviously, the erroneous belief that pseudo-color maps are independent of flaw detector information sometimes needs to be addressed when discussing inspection alternatives with manufacturing representatives. A cost comparison of the equipment used in contact versus immersion inspection usually is a good start in helping the uninitiated more properly assess the applicability of nondestructive testing methods.

The task of the manual inspection was twofold: find defects in the bar stock at an adequate level of sensitivity, and generate an inspection protocol that could be as readily reproduced in shop conditions as in the test lab. As mentioned earlier, a useful gain setting for ultrasonic inspection was one that relied not on reference standards or intrinsic gain settings. First, it was still unclear at this point just how to define a meaningful reference standard, and second, it was unclear to what degree variability in signal attenuation would occur between various bars.

The approach settled upon was to begin by establishing a reproducible and readily achievable signal for all inspections. Specifically, the contact inspection probe was positioned near the edge of a bar, where one would expect to see the least effect of internal discontinuities on the signal. A bit of movement along the edge indicated that a consistent, uniform backwall reflection could be generated, with only minimal signal fluctuation due to coupling inconsistencies. Gain on the flaw detector was then set so that this reflection saturated at 100% FSH (full screen height).

Once the backwall signal had been established as the effective reference point, the full areas of the blocks were scanned manually, with the extent of signals from throughout the block recorded. This process was repeated for several iterations, using increments of added gain above the reference point of backwall saturation.

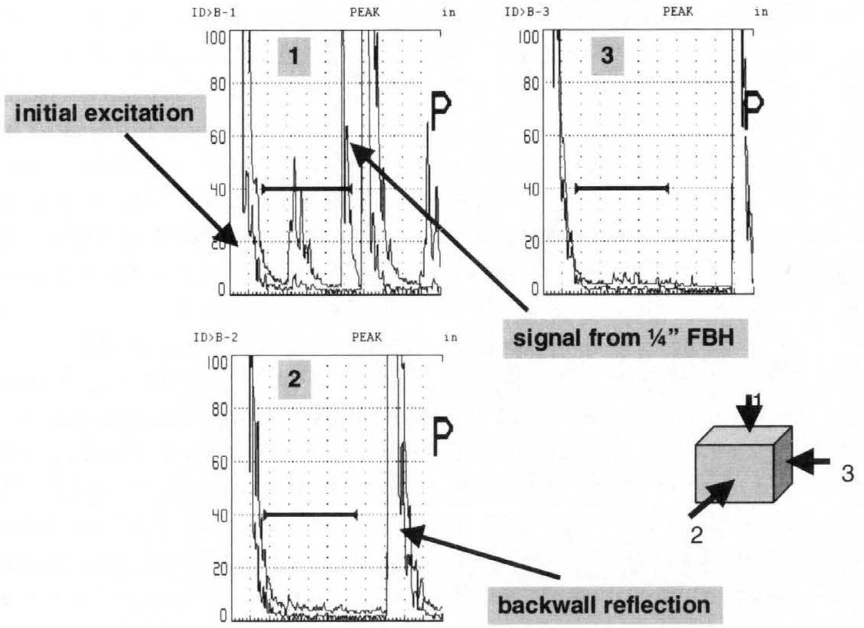

FIGURE 7. A-scan profiles obtained on the sample faces shown in Fig. 6. The flaw detector used here was operated in "frozen screen" mode, where data was retained at all points until and if stronger time/amplitude signals were obtained. The most suitable gain setting for inspection was deemed to be 30 dB above the saturation of the backwall reflection.

The gain setting that was thus arrived at for inspection was 30 dB above backwall saturation. At this level, the backwall reflection was well off-screen, and discontinuity signal amplitudes on the order of about 50% FSH or more were detected from blocks that produced markedly "noisier" C-scans. As shown in Fig. 7, a 6.35 mm flat-bottomed hole (1/4 in. FBH) was introduced into one block as an aid to suggest the severity of what was being detected in the rest of the block. The signal from this artificial reflector was over 100% FSH, while the natural flaw responses were smaller, but readily detectable.

It remains to be seen, of course, if the sensitivity as developed in this procedure is adequate for the requirements of this inspection. Early reports from the manufacturer, however, already indicate a significant cost-savings achieved though reduced inspection time required compared to previous practice, better assurance of product delivery, and a very strong suggestion that truly flawed steel is now being detected beyond previous technique. Destructive (pressure drop) tests are scheduled to take place at time of publication of this paper, confirming the utility of this inspection protocol, but all parties are optimistic of the outcome.

An important aspect of the development of a sensitivity level for an ultrasonic inspection is that the manufacturer has a simple, reproducible starting point upon which to develop their inspection protocol. Certainly, qualification standards abound that dictate the level of material cleanliness in steel. However, a generic manufacturer of equipment will not always be required to follow universal, established procedures. In many instances, the inspection is performed to decrease liability concerns and increase production throughput. Details to arrive at this point are left to the quality group at the plant, continuously subject to financial guidance. The above mentioned scenario seems to have satisfied most concerns about production of this manifold.

Another area wherein the concept of a "built-in" reference was developed was in the area of spot weld testing. Certainly, various manufacturers and research centers have developed ultrasonic systems aimed at the inspection, evaluation and interpretation of the condition of various spot welds. Work performed by the IDL, in conjunction with a number of small (< 100 employees) shops that utilize spot welding, was not meant to displace accurate, robust systems that are available. Rather, the approach was to look a wide variety of spot weld configurations and determine if an underlying common thread could be found to guide inspection. Presumably, such guidelines would be most helpful to small shops that own a flaw detector with water column transducers, and wish to perform spot weld inspection.

In the study, roughly 600 spot welds were examined, representing 33 combinations of material type, sheet thickness and coating condition. The participating manufacturers submitted welds that they considered good, so-called "stick" welds, and welds with undersize nuggets. Weld signals were obtained from all welds using a gain setting wherein the second backwall echo of a single sheet of *unwelded* material was just saturated to 100% FSH, and then 12 dB of additional gain added. Signals were obtained on these welds using both water-filled (actually, we found using gel couplant is as good or better) column transducers and solid delay line transducers.

Signals were recorded, and the peak values of various echoes entered into a database. The next step in our evaluation of an optimized weld inspection technique dealt with developing a simplified means of assessing the features from different signals. It was desired that the algorithm would be easy to implement, but could, of course, adequately discriminate between different weld conditions.

The peak amplitudes of the echoes corresponding to 1 thickness, 2 thicknesses, etc. (1st echo, 2nd echo, etc.) were entered into a database. For each weld condition, in each category, we determined the average values for each of these echoes. Looking at the interfacial reflections (1st, 3rd, 5th, 7th echoes) we determined the maximum value from that weld. We then evaluated the peak amplitudes of the three weld classifications (good, undersize, stick) by using logical qualifiers such as "greater than" or "less than." For example, we examined the maximum interfacial reflection for the stick weld was greater than that for the undersize weld, and in turn if the maximum interfacial reflection from the undersize weld was greater than that obtained on the good weld. If both conditions were met, we deemed this weld group a "correct call" as far as interfacial reflections were concerned.

The through-weld reflections (2nd, 4th, 6th, 8th echoes) were then studied. The average value for these peaks was obtained in each weld classification, and a linear regression fitted to this data. The slope of this regression was evaluated and it was determined that a line fit to even-numbered echoes of the undersize weld should be less than the slope for the same echoes on a good weld, due to attenuation effects. If this was the case, we considered this weld group a correct call for through-weld reflections.The size of the transducer element was roughly matched to the anticipated nugget size, and this was a fairly easy matter. Experimentation with readily available delay lines, as well as ones that had their ends chamfered or rounded over, were used. The solid delay line that had a 1/32″ radius round over to break its edge worked best in this study. This delay line was used for the bulk of our work.

Set-up of instrument:

- establish echo pattern on *unweld* material,
- saturate 2$^{\text{nd}}$ backwall,
- add 12 dB more gain.

On calibration welds:

- determine dacay (slope) of through-weld peaks
- develop limits to echoes from interface.

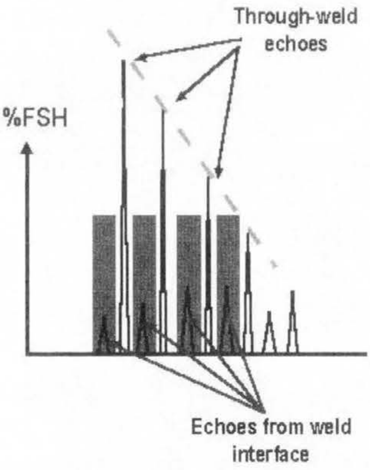

FIGURE 8. Schematic illustration of simple method for inspection of generic spot welds. The approach is not perfect, but is a useful start for inspectors who may not have a "standard" to refer upon. An easily repeatable signal from unwelded material is used as reference, with some added gain to increase sensitivity to pertinent features.

The approach is shown schematically in Fig. 8. It was initially determined that 60% of the welds could be correctly tested and characterized by applying the instrument set-up guidelines described, and submitting the data to the analysis procedures outlined. Permitting some minor adjustments to be made to our signal feature evaluation algorithms, this level rose to 87% correct weld classifications. Recall that this approach was aimed at a testing *any* generic spot weld. Refinements to the evaluation criteria on a case-by-case basis should readily improve this percentage.

To reiterate the goal of this work, it was felt that manufacturers could benefit from inspection protocol where the equipment setup was straightforward, the interpretation was based on a limited number of samples, and the inspection was referenced to a meaningful, readily producible signal. While it certain that more sophisticated spot weld inspection systems could lead to higher numbers of accurate inspection calls, the simple method forwarded in this work appears extremely convenient and user-friendly for inspection shops limited in experience and funding.

The illustrations provided of the two methods described so far in this paper are intended to portray experience garnered over the past decade with small- to mid-size manufacturers. Within the field of nondestructive testing and evaluation, a certain level of sophistication will enable knowledgeable personnel to select the right tool from the repertoire of possible techniques. Further, these people can gain experience in fine adjustments to standard protocol when applying these methods.

However, it should be remembered that the members of a manufacturer's engineering staff are often, if not usually, unacquainted with the particulars of nondestructive inspection methods. They may make mistakes that range from simple to subtle when using these techniques, irrespective of the degree of history of such methods in the NDT/E community. And, regrettably, their concerns for test expedience may force them to overlook the simplification of sophisticated methods to meet their needs. It is incumbent on the engineers and scientists in the nondestructive test community to develop their own skills to assist the communication process with those segments of industry that have yet to embrace NDT/E.

3.3. Leak testing

Numerous techniques are available for the detection and location of leaks in pressure containment parts, pressure vessels, and structures. Leaks can be detected by using pressure change measurement, flow rate measurement, vacuum systems, helium mass spectrometry, halogen tracer techniques, and bubble testing methods, among others. Industrial requirements often involve clear specifications for a given leak rate detection, and thus necessitate detailed equipment the manufacturer must use for testing.

In many instances, however, clearly defined leak detection criteria are not established, with the intent being only to produce the fictitious "leak-proof" item. Faced with such an ill-conceived notion of leak detection, manufacturing personnel often attempt the simplest of inspections and hope their efforts suffice. This situation leads to a poor understanding of the leak detection ability that is needed, and then confuses the simplicity of the leak detection method with a lack of attention to details.

Conversely, the practitioner of nondestructive inspection should be empathetic toward the design engineer who requires a "leak-proof" item, and stand ready to explain that *no* item is leak proof, but may exhibit a very, very low leak rate at best. The NDE/T professional should also realize that leak testing occurs after an extended product development and production sequence, perhaps as a final, reluctant, proof test. As such, leak testing will often be the product of good intentions, but an education in how to best select and apply it in the manufacturing environment will be needed.

Aside from discussion on specialized techniques and equipment such as helium/halogen "sniffers" associated with very low leak rates, not much quantitative study applied to test applications seems to be available. Of course, the Nondestructive Testing Handbook of the American Society for Nondestructive Testing (ASNT) Volume 1[3)] is an excellent resource for material dealing with the varied aspects of leak testing. But some of the more simple techniques for leak detection have seen little documentation. Therefore, systematic evaluations of the use of straightforward leak detection, such as bubble and acoustic methods should be of invaluable service to industry.

Bubble leak testing, whether accomplished using immersion or bubble film techniques, is of value to manufacturers for ease of use and simple detection of bubble formation to reveal the presence of leaks. Leaks having a very low leak rate may not be detected by these techniques, but many products are deemed quite adequate if their pass/fail acceptance is based on the formation and detection of bubbles. The chore for the nondestructive professional is to refine these procedures for the manufacturer.

In a representative instance, a manufacturer of a pressure tube assembly consisting of brazed joints was performing liquid immersion testing to detect leaks by simply pressurizing the component and dunking it into water. This method caught some leaks, but in order to retain significant customers, their practice had to be improved.

[3)] Nondestructive Testing Handbook, 2nd edition, Robert McMaster (Ed.), Volume 1, "Leak Testing", American Society for Nondestructive Testing.

Figure 9 shows the test procedure as practiced by the manufacturer. The component in question was effectively sealed, pressurized and immersed into water. Leaks were found by the detection of bubble streams. As stated, this method found some leaks, but not all. The question was how to improve this practice.

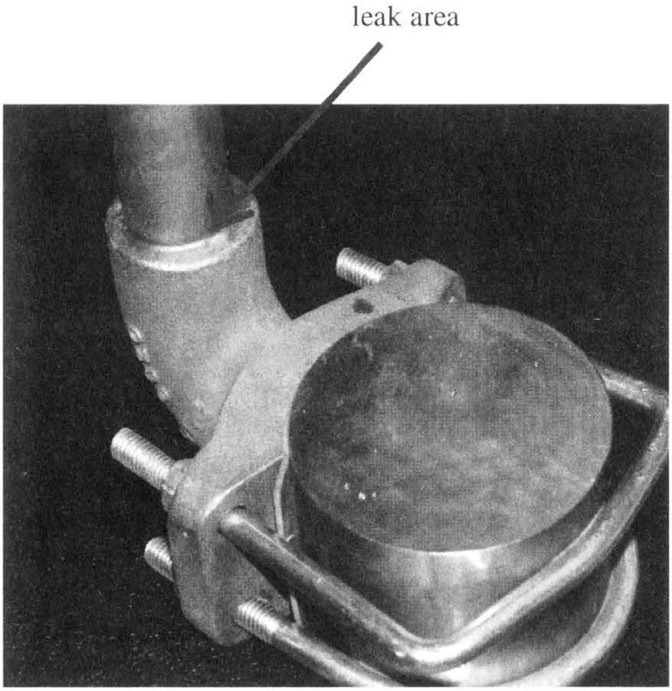

FIGURE 9. A representative method for immersion leak testing. The assembly is sealed and pressurized, immersed in a dunk tank, and leaks from the susceptible braze area are detected visually.

A number of possible concerns were identified at the manufacturer's shop, but the best way to systematically evaluate possible improvements to the test were done at the IDL facilities. Two assemblies that had been rejected by the customer as having a "large" and a "small" leak were tested in a variety of configurations. The assemblies were pressurized at a range of pressures from 140 to 415 kPa (20 to 60 psi) and immersed in a sample of the manufacturer's dunk tank water, fresh tap water, and water treated with an additive that lowered surface tension for the formation of bubbles.

A series of lessons were learned in the lab, and digital movies of the bubble streams were recorded to show the manufacturer the possible improvements firsthand. It was determined that the visibility of bubble streams in the factory's dunk tank water was significantly improved simply by cleaning the water. Although very logical in retrospective, the same leaks in using water that was not contaminated over the course of multiple inspections were greatly more detectable. This simple lesson was brought home to the manufacturer when seeing side-by-side videos of their leaks under these conditions.

The next lesson was again not revolutionary: greater pressure in the test part made the bubble streams more visible. In this instance, compressed air was used in the lab with at least as satisfactory results as parsing out the use of dry nitrogen in testing. This led to cost savings at the manufacturing plant.

Further, the visibility of bubble streams from these leaks was improved by the addition of the commercially available immersion additive. While this is not surprising in itself, the laboratory experiments manipulated the extent to which such an additive was added to the dunk tank water. Beginning with the manufacturer's (of the additive) suggestion of a 50% solution, the lab tests used solutions ranging from 4% to 50%. It was found that, for the leaks in question, the bubble streams seemed to reach optimum visibility in the 13-25% range.

The lessons up to this point indicated that readily made improvements to the immersion test could be obtained, perhaps "stretching" the perception of what was necessary from sellers of immersion additives. But the lessons continued quite a bit further when efforts to replicate these tests were attempted at the manufacturing facility.

The same samples with leaks were taken to the manufacturer to show what could and could not be done with them. But both leaks were then, in fact, detected at the facility, in their contaminated water, without much effort! While performing these tests, it was noted that two procedures were in place that interfered with the leak testing. To alleviate corrosion in these assemblies they were briefly dipped in a ferrous metal corrosion inhibitor. The samples in question were very briefly immersed in this solution, and then retested for leaking. Both leaks disappeared, presumably clogged by the corrosion inhibitor. The samples were dried in a low temperature oven for 30 minutes and retested; both leaks were again visible. The manufacturer now realized that they needed to test their assemblies soon after production, and only afterward apply suitable corrosion inhibitor.

In addition, the assemblies had been exposed to a brief shot peening following the brazing operation to remove excess spatter from the braze area, making the part appear cleaner. However, the known leaking samples were subjected to this operation, and once again, the leaks disappeared, presumably by contamination of the peening material and/or smearing of the soft metal over the leak area. The wisdom of performing this operation before leak testing, therefore, was also reevaluated.

By working with real samples in the lab, a number of easy improvements that the manufacturer could use were identified. By observing the leak test operation in the full context of production, other confounding issues were identified that could defeat leak testing. At the end of the day, the manufacturer was not changing very much in the manner of the test itself, but rather how nondestructive testing was implemented in their work stream. Some additional evaluations opened up a broader perspective on their practice, namely, using bubble film solutions on these parts.

In the field of bubble film testing, the consumer can be confused by the claims of commercial vendors. That is, a number of different products can be obtained, all purporting to be effective visual enhancements of the leak detection. The detection solution is applied to the area of interest, and the film solution creates a foaming action that can be readily detected. The promise is that a number of components or a large area can be rapidly tested without needing to immerse the part.

Two different solutions were applied to the leaking components in the above example, and the results observed. Of the two solutions selected for testing, one of the products appeared to be demonstrably better than the other, especially at low pressures. This was a somewhat subjective call, as a visual indication of some sort could be seen by either solution. However, one of the solutions provided a more vigorous activity and was immediately favored by the component manufacturer when shown movies of the test results. This solution was further tested on the leaks, and a dilution of down to 6% was seen to provide quite visible indications of the leaks.

The assessment at this point was that for leaking parts, the consumer could benefit from seeing comparative results obtained with different products. As before, going beyond the producer's claims and diluting the product can still provide good results for the test at hand. The result of all of this testing was that an entirely new approach to leak testing was arrived by the manufacturer with simple assistance from the nondestructive test expert. The production method was revamped to make better use of inspection, wherein the same user friendly principle of visual detection could now be applied to a greater number of parts at a time, assuming they did not need immersion and could be pressurized and tested in sequence with bubble film, instead of being immersed in water.

Another area of leak testing that seems predicated on information not clearly correlated to industrial experience is acoustic leak testing. As escaping gas leaves from the component/high-pressure side of a leak to the ambient/low-pressure side, turbulence is created. This turbulence produces energy with components of high frequency, typically around 40 MHz. Some knowledge of the mechanics of detecting leaks via a method of using a microphone and heterodyne manipulation of the high frequency signal into the audible range has been published[4]. However, the nature of the information in reference material is often cited in terms that are technically proper, but not readily correlated to industrial experience. An example of information available for acoustic leak testing is shown in Fig. 10. Here, detection distance with an acoustic detector is shown as a function of orifice size. Certainly, this information has value. However, if acoustic leak detection is to be applied for product leak testing, it is reasonable to assume that the detection distance will be on the order of about 0.3 m (1.0 ft.) or less, which the graph does not delineate clearly. Also, component test pressure is often a predetermined value, based on the pressurizing constraints of the product and/or pressurizing system. Therefore, the question of concern often regards the orifice/leak size that can be detected in a given instance, with given equipment.

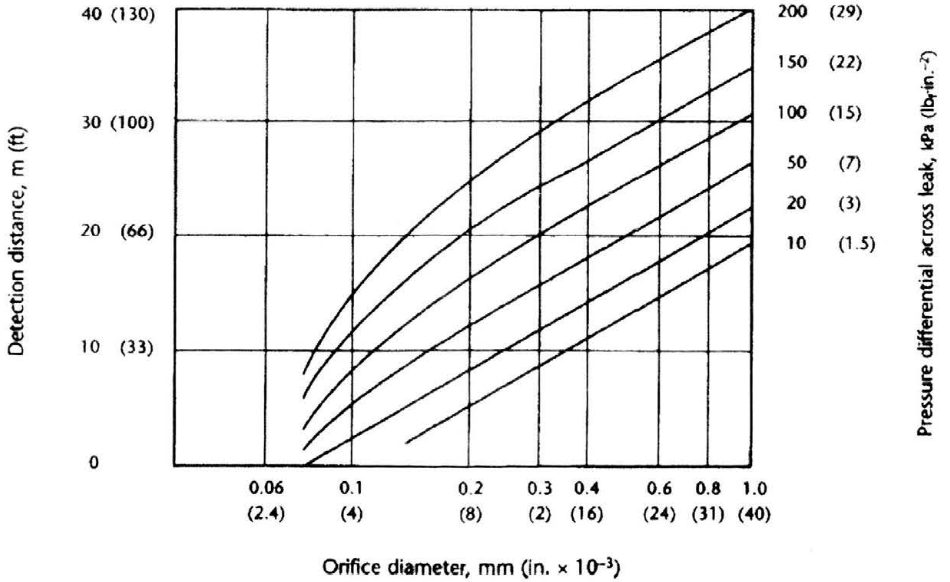

FIGURE 10. Typical acoustic leak testing reference information. Although technically correct, little in this graph would assist a manufacturer in product leak testing at close range. (From *ASNT Handbook*, Vol. 1)

Through experience in testing different acoustic leak detectors, the IDL has learned that all products offered for this purpose are not the same. Without going into a product evaluation at this time, suffice to say that different systems appear to have significantly different detection qualities. An over-

---

[4] *NDT Handbook*, Vol. 1, op. cit.

looked part of acoustic leak test systems seems to be the headphones the tester would wear. If the electronics of such a system are well developed but inadequate headphones limit the information they provide, the overall detection capability is also thus limited. It was found that a pair of studio-quality headphones can convey a wealth of information to the inspector's ears that is not easily quantified.

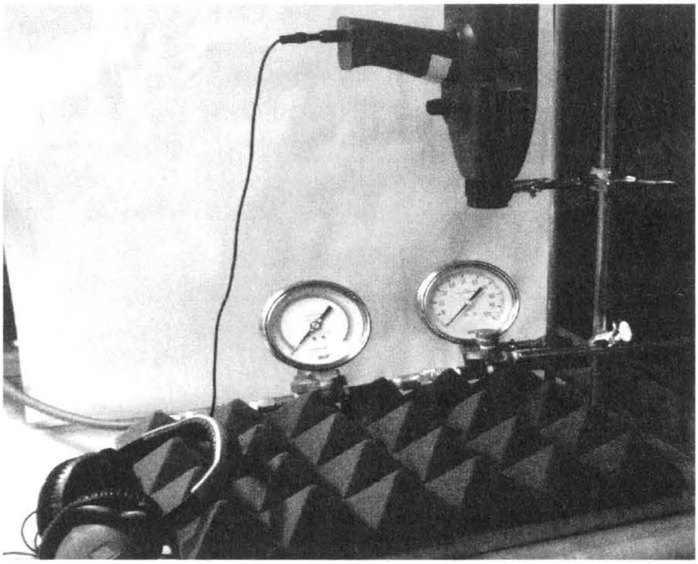

FIGURE 11. Acoustic leak detector, focusing on an artificial "leak" created by fitting an end cap with a laser-drilled orifice to the end of a pressurized tube.

Assume then that a good instrument is to be used; quantitative studies pertinent to a manufacturer's experience can be developed. Figure 11 shows the laboratory set up used at the IDL for this purpose. A prominent feature of this test fixture is the interchangeable metal end cap that goes onto the end of the air pressure outlet. A collection of these caps were both mechanically and laser-drilled, providing a range of simulated leaks. The wall thickness on these caps was ground down to permit finer holes to be cut by the laser. The smallest orifice thus obtained was 0.114 mm (0.0045 in) which is still considered as a gross leak. Conceivably, chemical etching could be used to obtain finer orifices. For the purposes of this work, however, these simulated leaks provided a good starting point for discussion. In the future, actual leaks will be removed from products and fit into a gasket that permits pressurization and leaking.

A series of tests were run that compared leak detection capabilities of different size orifices at various pressures and different gain settings, on a given acoustic leak detector. Although such devices have an analog needle gage that can provide deflection signal, or a digital output that registers some value, the fairly subjective response of "hearing" the leak turbulence through headphones is often the most intuitive way to demonstrate the technique's applicability. However, it can be more reliable to quantify such results, as well as to facilitate discussion, if a parameter such as needle deflection is recorded. Therefore, the following graphed data shows needle deflection at mid-gain on the chosen device.

Figure 12 shows the results obtained using 6 different orifice/leak sizes. Although all of the leaks were audibly detected over the entire range tested, signal deflection markedly decreased below a certain minimum pressure. Also, needle deflection increased as a function of orifice size, which was not unexpected. A mid-size orifice produced the highest activity, however. Closer examination revealed that this particular end cap had been drilled in the op-

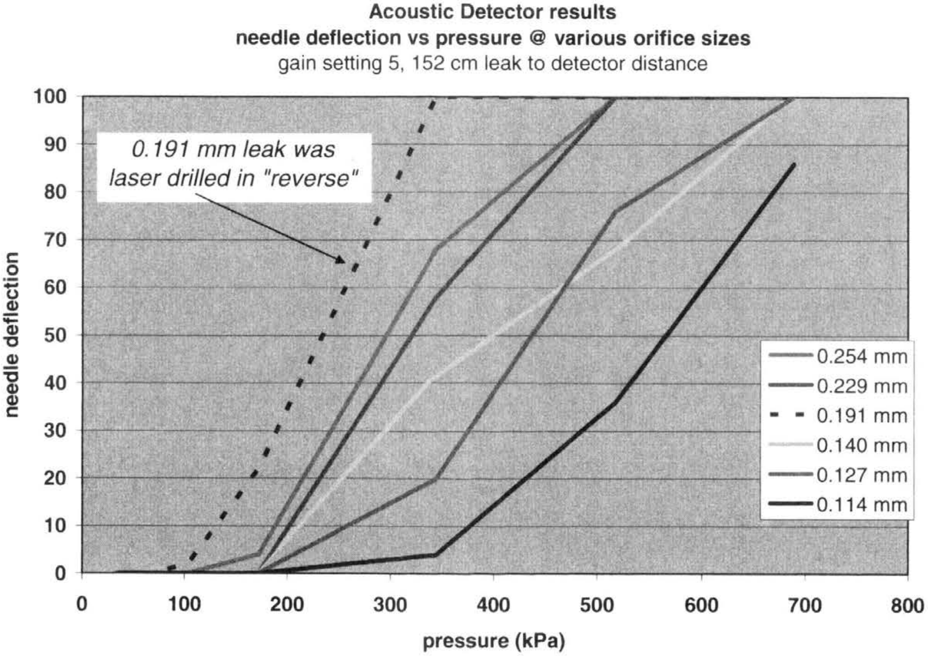

FIGURE 12. Acoustic leak detection data, showing needle deflection as a function of pressure through various orifice/leak sizes. Detection capability is seen to increase with increasing pressure and increasing orifice size. Leak detection can also be seen to be unpredictable if the nature of the leak varies, as evidenced by the 0.191 mm (0.0075″) orifice generating high needle deflections at relatively lower pressure, presumably due to unique associated turbulence.

posite sense of the others, such that the laser-burned "funnel" was configured reversed to the others. This inversion was such that the turbulence created at the leak was apparently much higher, or at least contained a higher proportion of high frequency activity, than the other leaks at the same pressure.

These results were intended to demonstrate some relationships readily to manufacturers regarding acoustic leak testing. When considering the applicability of this technique for their purposes, manufacturers will likely know how much pressure their component can sustain for testing. If somewhat similar conditions in the lab yield a certainty for successful leak detection, such a device may very well be of use in their practice.

4. Summary

The material presented in this paper is intended to highlight some of the concerns that have arisen in three areas of inspection, and convey experiences gathered over several years of industrial interaction with manufacturers. The examples cited here are not intended to be all-inclusive or representative of all industrial situations. Indeed, interaction between nondestructive personnel and manufacturers would likely proceed much more smoothly than cited here if NDE/T were integrated into design and production. This would suppose, however, that the participating industrial partners were committed to treating inspection as a necessary, useful component of the production process. Sadly, this is not always the situation, and the nondestructive advocate must state a stronger case to get the message across.

Several areas should be addressed when pursuing an industrial interaction. Among them, it would be most beneficial to develop a commitment by the manufacturer's management to pursue the inspection. At times this will already be in place due to catastrophic ramifications that have arisen from product liability or customer dissatisfaction. Ideally, a fore-thinking company will not need to be pressured into an acceptance of the benefits of NDE/T.

In developing a particular solution for any industry, past misinformation and/or poor continuity within the company must be countered. Not only will a new inspection protocol perhaps be in development, but also an educational process within the company should be taking place. The merits of an inspection process will need to be verified to the satisfaction of the personnel who will be using the technique. The time and money saved by successfully implementing the nondestructive practice should be understood by all personnel involved.

Beyond this, the use of a new or refined technique will need to conform to the environment in which it will be used. While it is appropriate to challenge shop personnel to perform new tasks during inspection, it should also be remembered that the usefulness of the inspection in the long-term would rely on the end-users, without the NDT/E expert present. The shop personnel will need to develop confidence and expertise in applying the method to their work.

It is also conceivable that a company will only really embrace the new inspection by seeing improved results over time. This will include, conceivably, a reduction in scrap costs, better material handling and planning abilities, and reduced or eliminated customer complaints. Also, it should be expected and that, after time, feedback from shop floor personnel on using the technique will be invaluable for the next application, and the nondestructive expert can learn from others' experience. Ultimately, a worthwhile collaboration between the nondestructive test expert and a manufacturer should result from good communication and a clear understanding of expectations and limitations of the physical processes and challenges involved, and the benefits to be achieved.

◆