Introduction
Positive material identification (PMI) is an essential component of construction, maintenance, and safety in chemical, petroleum, and power generation plants. Failure to use the proper alloy in each application can result in production loss but, more importantly, it is a threat to the health, safety, and well-being of the public. In the United States, the Occupational Safety and Health Administration, the Department of Transportation Pipeline and Hazardous Materials Safety Administration, the American Petroleum Institute, the National Transportation Safety Board, the Bureau of Safety and Environmental Enforcement, and NACE International have all recommended the implementation of PMI programs in their respective spheres of influence (API, 2010; API, 2013; OSHA, 1998; PHMSA, 2009; PHMSA, 2015).

Handheld X-ray fluorescence (XRF) is a highly effective technique for PMI. The combination of fundamental science, modern electronics, and digital computing result in a technique that is simple, accurate, and precise. The nondestructive testing (NDT) technician is able to obtain definitive elemental analysis and alloy grade matching with little to no specimen preparation. Typically, this can all be accomplished in less than 30 seconds, with many commercial alloys being identified with only 2 to 3 seconds of test time. This ease of use enables fast and extensive testing, even on in-service samples.

Given the critical nature of PMI, NDT technicians often wonder about the accuracy and precision of XRF instruments. How confident can they be in their measurements? This article clarifies the meaning and implications of accuracy, precision, and confidence level as they apply to XRF for PMI.
Accuracy asks, “How close are the measurements to the true value?”
Precision asks, “How close are the measurements to each other?”
Confidence level asks, “How sure are you that the measurement is correct?”

XRF measurements involve several sequential steps that appear seamless and instantaneous to the NDT technician, but are separate on the level of physics and electronics:

1. X-rays are emitted from the instrument and the sample is irradiated. (In handheld XRF, X-rays can come from one of two sources: miniaturized X-ray tubes or radioactive sources. In North America, the majority of XRF analyzers employ miniaturized X-ray tubes. These operate by passing an electric current across the cathode, accelerating electrons toward the anode, which then emits the X-rays. Historically, XRF analyzers, and some units still on the market, employ radioactive isotope samples as their X-ray sources. These generate X-ray by a radioactive nuclear decay process.)

2. The atoms in the sample absorb the X-rays and are excited to a higher energy state.
3. The atoms in the sample re-emit their own characteristic X-rays, reflecting the elemental composition of the sample.
4. The characteristic X-rays are measured by a digital detector in the instrument.
5. The signal from the digital detector is analyzed and interpreted using computer software and analysis.
6. The NDT technician is provided a grade match and elemental composition. The resulting measurement enables the technician to assess his or her confidence level in the analyzer’s accuracy and precision.

**Accuracy in X-ray Fluorescence Measurements**

XRF is very accurate, measuring most of the common metals in alloys (for example, iron, nickel, copper, and so on) to less than 0.01%. Although most of the elements on the periodic table can be detected and measured using XRF, only a handful of them are common elements in commercial alloys. Lighter elements are more difficult—and thereby take longer—to detect than heavier elements, but this has minimal effect on grade matching and PMI (Jenkins, 1999). General XRF limits of detection for alloying elements are reflected in Figure 1 (Borkhodoev, 2014). Given the density of most metals and the energetic proximity of the X-ray emissions of many alloying elements, inter-element interference is common. In spectroscopy this is known as “matrix effects.” Therefore, limits of detection can vary based on sample type and elements present. The limits of detection represented in Figure 1 are conservatively reported given the complex composition of many commercial alloys. For a further discussion of limits of detection XRF, see the references (Jenkins, 1999).

The accuracy of XRF for grade matching in PMI is rarely dependent upon a single element. Most alloys involve multiple elements for grade matching. For example, correctly identifying stainless
Steel 321 (Figure 2) depends on the alloy requirements for iron, chromium, nickel, and titanium, along with specific allowances for manganese, copper, and molybdenum. This grade identification does not depend solely on the accuracy of a single element (for example, chromium) but upon measuring multiple elements (for example, iron, nickel, and titanium along with the chromium). This improves the accuracy of the identification. It is analogous to having multi-point identification in forensics (that is, sex, height, weight, hair color, fingerprints, and blood type).

It is important to keep in mind that accuracy and precision are two different and independent qualities of a measurement (Guare, 1991; Treptow, 1998). Both are important, but they are not the same thing. Accuracy reflects how close the measurement is to the sample’s true value, while precision determines how close repeated measurements are to each other. This distinction can be illustrated using a target (Figure 3). Accuracy in this illustration asks, “How close are the hits to the bull’s-eye?” Hitting the bull’s-eye is equivalent to correctly measuring the true value. A measurement is deemed accurate if it is in agreement with the true value (Jenkins, 1999). In other words, “Is the measurement correct?”

Precision in X-ray Fluorescence Measurements

Precision in this illustration asks “How close are the hits to one another?” Note in Figure 3 that it is possible to have high accuracy (close to the bull’s-eye) with low precision (Figure 3a). It is also possible to have high precision (close to each other) with low accuracy (Figure 3b). A measurement is deemed precise if it is in agreement with other repetitions of that same measurement— independent of whether they reflect the true value. In other words, “Is the measurement reproducible?” A properly designed and calibrated XRF analyzer is able to provide a measurement that is both accurate and precise (Figure 3c).

Reporting Accuracy and Precision in X-ray Fluorescence

Handheld XRF instruments are generally accurate to less than 0.01% for most common alloy elements. Figure 2 shows a typical readout on an XRF instrument. Here, measurement of the composition is reported in the second column of the chemistry table on the analyzer screen (Figure 2, column 2 highlighted in yellow). Each reported value in column 2 is an average of multiple measurements. Although a test can be completed in 30 seconds (or less), the instrument actually measures the sample hundreds to thousands of times in this timeframe (hundreds to thousands of X-rays). Using the aforementioned analogy, this is equivalent to throwing hundreds to thousands of darts at the target. The average of all these measurements is what is actually reported in column 2.

Since the instrument is measuring the sample multiple times in a single test, column 3 in Figure 2 details how close those measurements were to one another (that is, the precision). Ideally, every one
of the measurements would be exactly the same (that is, each dart would land directly on top of the previous dart). In reality, this is often not the case due to the complexities of the physical sample, X-ray behavior, and the configuration of the electronics. The measurements can be close to one another (high precision) but are rarely identical. There is always a spread or deviation between the data points, which follows a normal distribution or “bell” curve (Figure 4). The X axis represents the value of the measurement. The Y axis represents the number of times that value is measured (that is, the frequency of the measurement). The green bar (Figure 4) reflects the average of all these measurements, coinciding with the top of the bell curve. The width of the curve reflects the spread or deviation in the measurements. The smaller the spread, the greater the precision. The precision, or deviation, in the measurements is reported as the ± value in column 3 (Figure 2). The precision indicates how tightly clustered the measurements were to one another. As the number in column 3 gets smaller, the precision improves, indicating the measurements were closer to one another with a greater degree of reproducibility.

Figure 5 illustrates that it is possible for two sets of measurements to have the same average reported value. These two datasets would have the same accuracy but with different levels of precision. Both datasets have the same average (green bar)—or accuracy—but the dataset illustrated in red has a larger spread, or deviation, than the dataset in blue. The width of the red curve—reflecting the spread or deviation—is larger than the width of the blue curve. The dataset in blue has greater precision than the dataset in red—even though both are equally accurate. This is because accuracy and precision are independent of each other (Figure 2a versus 2b).

The spread of data is quantified by the standard deviation, denoted \( \sigma \) (Blaisdell, 1998). The standard deviation is the accepted technique of reporting the precision of scientific measurements (Guedens et al., 1993; Skoog et al., 1997). In a normal distribution, 68% of measurements will fall within one standard deviation of the average (±\( \sigma \)). Moreover, 95% of measurements will fall within two standard deviations (±2\( \sigma \)), and more than 99% of measurements will fall within three standard deviations (±3\( \sigma \)) (Figure 6). These are percentages of the measurements and in no way reflect the confidence level of the measurement (discussed in the following section). It is important not to confuse these percentages. As precision improves (smaller \( \sigma \)), more and more measurements will fall closer to the average (mean).

Confidence Intervals in X-ray Fluorescence Measurements

It is important to keep in mind that precision and confidence are not the same thing. Confidence refers to the accuracy of the measurement (not the precision). Confidence asks, “How sure are you that the measurement is correct?” This is a question of accuracy, not precision. It is customary to report both a confidence level (for example, 90% confidence) and a confidence interval (XXX–Y,YY). The confidence interval is also referred to as the margin of error (Blaisdell, 1998). The confidence level and the confidence interval are reported together. Imagine that the chromium content for a sample of stainless steel was reported as 18.00% with a margin of error of 0.01% (for a 99% confidence level). These values can be interpreted as saying, “The user is 99% confident that the true value falls between 17.99 and 18.01%, or 18.00 ±0.01%.” Again, it is important not to confuse precision and confidence interval. The ±0.01% is not the precision in this example. Rather, it represents the margin of error or the confidence interval. Confidence applies to accuracy. Notice in Figure 3 that accuracy is independent of precision. Someone throwing darts, as in Figure 3a, can be completely confident that he will hit the bull’s-eye, even though his precision is low. For any reasonable length of test time, the confidence interval (or margin of error) will always be smaller than the precision.

Calculating the confidence interval is a multi-step statistical calculation, the details of which are not relevant to this discussion—many spreadsheet programs or statistical calculators can perform this calculation for the user (Blaisdell, 1998; Skoog et al., 1998). The important thing to note is that the confidence interval is
The Relationship of Accuracy, Precision, and Confidence in Alloy Analysis

Consider the analysis of a sample of stainless steel 316, shown in Figure 7, which further illustrates confidence as it applies to the accuracy of the measurement (in contrast to precision). The XRF analyzer reports that the sample contains 10.251% nickel (Ni) (column 2) with a precision of ±0.047% (column 3). Notice that the analyzer is precise to within less than 0.5% of the measured value (0.047 out of 10.251%). But confidence applies to accuracy, not precision. In this example, the user can be 99% confident that the true value is within 0.005% of the reported value (10.251%). Notice that the interval required to be 99% confident is almost 10× smaller than the precision. The user can be 99% confident that the true value falls between 10.246 and 10.256% (10.251 ±0.005%). The margin of error (in accuracy) is very small (0.005%). In other words, the user can be highly confident that the sample contains 10.251% nickel (even with a precision of ±0.047%). Moreover, the identification of stainless steel 316 in this example also utilizes the chromium, iron, and molybdenum requirements along with manganese and copper allowances. These multi-element measurements enable PMI with a high level of accuracy and confidence.

It is worth noting that larger measurements will have larger variations (standard deviations, σ) in their relative precision. Notice in Figure 2 that iron (Fe) makes up 70.800% of stainless steel 321, whereas manganese (Mn) only makes up 1.391%. These measurements have different levels of relative precision. The iron has a precision of ±0.065%, whereas the manganese has a precision of ±0.027%. This does not mean that manganese is measured more accurately. Remember, accuracy and precision are different things. Notice instead that iron has a larger relative measurement (70.800 versus 1.391%) and, therefore, has a larger relative precision (±0.065 versus ±0.027%). In both cases, the measurements have a precision of approximately one-tenth of a percent (0.1%) of the measured value. Therefore, larger measurements will have larger precision values. To use the analogy discussed previously, when the target is larger, there can be a larger spread in which the darts land while still hitting the bull’s-eye. When the target is smaller, the hits have to be more tightly clustered to remain within the bull’s-eye.

The aforementioned discussion focuses on precision not confidence, these two being different things. Although the measurements have different precisions (±0.065 versus ±0.027%), the user can have a high level of confidence in both reported values. Specifically, the user can be 99% confident that the true value for iron falls between 70.780 and 70.784% (that is, 70.78%). To the same degree, the user can be 99% confident that the true value for manganese falls between 1.417 and 1.423% (that is, 1.42%). Notice again that the margin of error (confidence interval) is smaller than the precision (Table 1).

Conclusion

XRF provides a fast and effective means of positively identifying alloys and their elemental composition. It is important in the context of PMI reporting that the NDT technician understands the differences and relationships between accuracy, precision, and confidence level. Best practices include using a standard operating procedure and reporting the actual measurements as well as the precision (standard deviation) and testing conditions. In this way XRF can be an effective tool for PMI, contributing to safe industrial operations.

<table>
<thead>
<tr>
<th>Element</th>
<th>Measurement</th>
<th>Precision</th>
<th>Margin of error*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron (Fe)</td>
<td>70.782%</td>
<td>±0.065%</td>
<td>±0.0022%</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>1.420%</td>
<td>±0.027%</td>
<td>±0.0026%</td>
</tr>
</tbody>
</table>

* for a 99% confidence level.
**LETTER TO THE EDITOR**

**Dear The NDT Technician Editor:**

Re: Vol. 15, No. 4 of The NDT Technician.

In the article “Quick Industrial X-ray Testing Without Intermediate Data Carriers of Information,” the Ukrainian author, V.A. Troitskyi, improperly coined the term “flash radiography” for what ASNT refers to as “digital radiography.” Digital radiography is explained in Chapter 11, Digital Radiographic Imaging, of the third edition of ASNT Nondestructive Testing Handbook: Vol. 4: Radiographic Testing. Troitskyi’s use of “flash radiography” throughout the article should be corrected for your readership.

Flash radiography is also explained in the third edition of ASNT Nondestructive Testing Handbook: Vol. 4 Radiographic Testing on page 409: “Flash radiography is a special type of radiography used to produce a single stop motion image or a series of sequential images of high speed dynamic phenomena.” Specialized flash radiographic X-ray tubes and techniques have been developed primarily for the study of ballistic events, but of course are applicable to other very high rate events. There are significant and important technical differences between flash radiography and digital radiography. Hopefully, The NDT Technician readership will not be confused by the unfortunate selection of terms employed in the aforementioned article.

Sincerely,

Richard H. Bossi

Co-technical Editor of the ASNT third edition NDT Handbook: Vol. 4: Radiographic Testing

---

We use the term “flash radiography” in more simple meaning than is given in the third edition of ASNT Nondestructive Testing Handbook: Vol. 4: Radiographic Testing. It is important to understand that at the implementation stage of our digital radiography systems we get images almost immediately. In my article, three different ways of getting digital images were reviewed. Only one of these ways is instantaneous. This way is called digital radiography in the literature and my article. The first two ways include intermediate stages and they are not instantaneous. That is why this term was used for NDT personnel who work in industry. I agree with Richard H. Bossi, but this does not mean that we cannot use the term “flash radiography.” I use this term to differentiate digital radiography and my system from the first two ways. The main difference between them is the cost. The term “flash” means that the intermediate carrier of information and the additional equipment as well the extra expenses are absent. “Flash radiography” systems are the systems with lower cost and higher productivity.

I’d like to point out also that I’m not the first to use the term “flash radiography” for such digital radiography systems.

Best regards,

V.A. Troitskyi

President of the Ukrainian Society for NDT;
NDT Department Head of the E.O. Paton Electric Welding Institute

---

I would agree the reader correctly pointed out the correct terminology as found in the Radiography Handbook. This and several different terms or wordings were noted when reviewed. While not specifically addressed, a general statement (see: “A Short Note on the Text,” October 2016) was made about terminology in the article. When an author’s native language is not English, terminology in his/her country may occasionally differ from terms commonly used in the U.S. or found in ASNT handbooks.

Our Society continues to grow with many new members around the world. TNT welcomes and encourages articles from all countries understanding there may be terminology or terms that occasionally differ from the technical handbooks or those commonly used by technicians in the field. We welcome readers bringing these differences to our attention.

Bruce Crouse

Technicians Advisory Committee

E-mail questions to the editor: tkervina@asnt.org.
Redefining Precision

Vanta™ handheld XRF analyzers combine durability, power, and ease of use for fast, accurate elemental analysis in a variety of applications including quality assurance/control, positive material identification (PMI), scrap recycling, and consumer product safety.

Precise
- Axon™ technology for higher X-ray counts per second
- Accurate, repeatable results in as little as 1–2 seconds

Tough
- Drop tested to military standards (MIL-STD 810G)
- IP65 rated* for protection against rain, dirt, and dust

Simple
- Advanced touch screen enables quick menu navigation
- Optional wireless LAN (Wi-Fi) and Bluetooth® simplify data sharing

www.olympus-ims.com/vanta  | info@olympus-ossa.com  | (281) 922-9300

* M series analyzers are IP64 rated.

The Bluetooth® word mark and logos are registered trademarks owned by Bluetooth SIG, Inc. and any use of such marks by Olympus Corporation is under license.

Vanta and Axon are trademarks of Olympus Corporation.
FYI

Enhanced Tire Quality Controls by Novel X-ray Digital Detectors
by Fei Wang

X-ray linear detector arrays (LDAs) have been an ideal choice for inline and offline nondestructive testing (NDT) in the tire industry. Novel digital X-ray detectors have recently been developed for enhanced tire quality control. They are based on a new intelligent digital platform, which is targeted to improve image quality, increase the maximum scanning speed, and save on the overall system cost by both electronics and software design. Furthermore, they also provide remote firmware upgrades, diagnostics, and other advanced features. This paper presents the working principles of a typical industrial X-ray imaging system in the tire industry. It describes a new U-shaped detector, and explains how to improve the production efficiency as well as detection abilities in X-ray tire inspection systems. To illustrate, examples of applications in X-ray tire inspection systems are presented for various types of tires.

Introduction

X-ray inspection systems have been deployed in industrial NDT applications over many decades. The integration of the latest technologies from an X-ray source and LDA to a computer and inspection software have made X-ray inspection systems easy to use, safe, and fast. In the past, these factors limited their adoption for industrial applications. Nowadays, these factors have also broadened the scope of X-ray inspection systems beyond research and development applications, and more and more into the realm of inline production testing.

Overview of Tire X-ray Inspection Applications

Tire inspection has already become an important issue in the tire industry in order to improve tire quality and safety. For this purpose, NDT techniques have been employed to test a material for surface or internal flaws without interfering in any way with its suitability for service (Valavanis and Kosmopoulos, 2010). Typically, several existing technologies are used, including visual inspection, acoustic emission, and ultrasonic testing (Anouncia and Saravanan, 2006). The overall effects available for these methods are either quite limited or appropriate only for a specific type of defect (Zhang et al., 2013). On the other hand, X-ray is considered to be the most promising technology for tire defect detection and has been widely used in manufacturing processes (Zhang et al., 2013). X-ray has proven to be the most effective technique
due to its advantage in that surface and internal discontinuities, as well as significant variations in composition, can be detected. Although several inspection techniques are used during the tire manufacturing process, examination by X-rays is considered to be the final quality check of the finished tire. An example of a dual-station X-ray tire inspection system is presented in Figure 1.

X-ray inspection is a well-established NDT technique in the tire industry and is used in a number of applications for quality control and to ensure high levels of quality and safety. X-ray may be applied to prototypes during the development phase as well as for spot-checking or even 100% coverage inline production testing. To ensure all tires are structurally sound and reliable right out of production, X-ray is used to inspect the internal parts of the tire for any underlying discontinuities that could take place during initial use. Nowadays, large commercial truck and bus tires, as well as some passenger and light truck tires, are inspected in inline production by X-ray machines; however, X-ray tire inspection is not just applied for the final check of a brand new tire. High-priced tires for trucks, earthmovers, aircraft, and so on have their treads commonly replaced, with some of these products being re-treaded several, or even up to 10, times in the case of an airplane tire. From a commercial point of view, it is a reasonable step to analyze the performance of the inner structure of the tire by X-ray before applying the costly re-treading process.

Working Principle of a Typical X-ray Tire Inspection System

Based on the type of tires as well as requirements of inspection systems, there are several typical designs of X-ray inspection systems. In the tire tread and protruding wire inspections, an X-ray LDA is used with a standard X-ray source as the most typical X-ray inspection. It captures a single line at a time (horizontal), and requires the tire to be moved or rotated in order to create the vertical direction of the image. For large commercial truck and bus tires, as well as some passenger and light truck tires, in order to provide the best production efficiency and image quality, the LDA is shaped to approximate the contour of a tire from bead to bead as a U-shaped detector. By placing a panoramic X-ray source inside the tire and rotating the tire during inspection, an entire tire image can rapidly be collected in a single pass with the U-shaped detector; therefore, this is a popular usage nowadays in X-ray inline production testing. The operating principle of a typical imaging system with a U-shaped detector is presented in Figure 2.

For extra-large off-the-road tires, a single, long X-ray linear detector is utilized to reduce the overall system cost. The tire X-ray inspection systems require three or five rotations of the tire to gather necessary information to generate an image by moving the X-ray linear detector along the contour of a giant tire. The image is then generated for at least three sections for analysis: upper sidewall, tread, and lower sidewall.

Development Trend of X-ray Inspection Systems in the Tire Industry

Thanks to the strong demands of inline production testing, the tire industry market is driving X-ray tire inspection system development not only to offer maximum precision and reliability, but also to improve production efficiency. As the X-ray inspection systems are generally operated on an inline basis, they are part of a large production line, where every idle minute costs money. Therefore, the target is always to keep maximum uptime as well as reduce cycle time.

The traditional quality inspection process is mostly performed by human inspection. This often results in an inaccurate and undetected inspection result because of visual fatigue. This also leads to low efficiency with high labor costs. Today’s tire manufacturers produce tires that are complex and require sophisticated testing to verify the overall quality of the final product. As a result, a computer-vision-based automatic defect recognition (ADR) technique has also become an important and efficient tool to improve the quality of the products and increase manufacturing efficiency.

Novel X-ray Detectors for Tire Inspection

The requirements for X-ray detectors can be easily summarized based on the development trend of X-ray inspection systems of tire inspection. These are as follows:

- Easy for maintenance
- Ultra-high throughput and speed to improve production efficiency
- Superior X-ray imaging quality for ADR
- Reliability for high temperature and humidity, and robustness for external noise
- Flexible design to support various sizes of tires
- Multi-view system support for dual-station inspection system

A recent product family of U-shaped X-ray LDAs was developed and specially optimized for high-speed digital tire inspection utilizing panoramic X-ray sources (Figure 3). A block diagram of the series products is illustrated in Figure 4.
The series products are based on a novel intelligent digital readout platform, which brings significant advances in both speed and image quality for industrial inline and offline NDT of tires.

New features are user-friendly designed for maintenance, such as remote firmware upgrades, and automatic diagnostics combined with updated compact mechanics. With a gigabit Ethernet (GigE) interface and digital parallel readout structure, it reaches a maximum 1.8 m/s (5.9 ft/s) scanning speed, which can help to reduce the cycle time to approximately 20 s for up to 20% improvement of production efficiency. It also supports a dual-station system by using the GigE interface to allow multiple U-shaped detectors to be controlled by a single computer simultaneously.

By meeting CE Mark certification as well as dust and water-resistant standard IP43, it is optimized with a robust and reliable design for high temperature (0 to 65 °C [32 to 149 °F]), humid, and contaminated environments found in a tire production factory. It has improved the radiation hardness and lifetime of the detector, which helps to minimize lifetime cost of X-ray systems. Improvement of the X-ray response drop with absorbed radiation dose is shown in Figure 5.
The standard series is well suited for quality inspection of various types of tires, from passenger car and truck tires to off-the-road tires. With active lengths from 1382 to 3379 mm (54.41 to 133 in.) the series covers tire bead sizes of 30.48 to 88.9 cm (12 to 35 in.).

Thanks to the latest designs of ultra-low noise, front-end, application-specific integrated circuits as well as the digital readout platforms, it not only reduces the dark noise significantly, but also enables the highest sensitivity level with 0.75 pC gain. Thus, while meeting the high scanning speed requirement, the series can provide image quality to meet the tightest quality requirements. The dynamic range of the U-shaped detectors is doubled as it is presented in Figure 6.

In order to meet the demanding image quality requirements for inline ADR, a stringent hardware assembly control process ensures less than 0.25 mm (0.01 in.) mechanical gap along the entire 0.4 mm (0.02 in.) pitch LDA. Furthermore, an advanced pixel discontinuity correction algorithm was developed to get an edgeless image, as the discontinuity issue on certain detector array joints may disturb inline ADR for tire carcass and belt structure integrity.

The pixel discontinuity correction algorithm utilizes actual measured physical gaps in between detector arrays to recalculate the pixel position of each pixel, and then by inserting one new pixel into each physical gap, the correction values are calculated and stored in a flash memory of the detector hardware as a factory configuration for each U-shaped detector (Figure 7).

Figure 8 gives an example of image quality improvement by comparing the difference when the advanced pixel discontinuity correction is applied to the 0.4 mm (0.02 in.) pitch U-shaped detector.

In order to optimize the image quality further, an upgraded software library supports storing up to 256 offset and gain correction tables based on the optimized configurations for different types of tires. New software functions, including advanced nonlinear calibration, dead pixel correction, automatic troubleshooting procedure, and multiple detector support are also well suited to tire inspection. An example of an X-ray tire image with a 0.4 mm (0.02 in.) U-shaped detector is presented in Figure 9.

Figure 8. Example of a high-resolution tire X-ray scan without and with pixel discontinuity correction.

Figure 9. Example of a tire X-ray image with a 0.4 mm (0.02 in.) U-shaped detector.

Summary
This paper presented X-ray tire inspection applications and how recently developed novel X-ray digital detectors meet the application requirements by considering development trends of X-ray inspection systems in the tire industry for both high production efficiency and excellent image performance. The results show that it reached the expected improvements by cooperating with a couple of X-ray tire inspection system manufacturers.

AUTHOR
Fei Wang: Detection Technology, Inc., 6 Fortune Dr., Billerica, Massachusetts 01821; (408) 702-5561; e-mail wang.fei@deetee.com.

ACKNOWLEDGMENTS
Figure 1 is courtesy of Mesnac.

REFERENCES
NDT Professional Connections

Products and Services

Professional Connections allow companies to showcase their business cards. Check out the various products and services on display each issue to see what may be of value to you.
Technicians Advisory Committee Call for Members

The Technicians Advisory Committee (TAC) is seeking new members. Oversight for production and review of The NDT Technician (TNT): a quarterly publication for the NDT practitioner is provided by TAC within the Publications Division of ASNT’s Technical and Education Council. On the basis of interest, qualifications, and ability to contribute, any individual may become a member of TAC. An interest in the work and various roles of NDT technicians is a key requirement.

ASNT membership, although encouraged, is not a prerequisite for committee membership. Committee membership may be sought through written or electronic application to the committee chair. Committee membership is subject to review and acceptance by the committee, if the chair deems it necessary.

To apply for membership to the Technicians Advisory Committee, please contact Ray Morasse, at rgmorasse@gmail.com.
Practitioner Profile
Michael W. Allgaier

Michael W. Allgaier is an experienced training and certification consultant with more than 20 years’ experience. He is a leader in the visual testing method, active on ASNT committees, and a prolific writer and presenter for its publications. He has earned many nondestructive testing certifications, and has frequently been awarded for his service to the Society.

Q. How did you first become involved in NDT?
A. A couple of years in engineering school resulted in my losing my deferment. In lieu of getting drafted I joined the Navy. In 1970, after completing Navy boot camp and 15 weeks of Ship fitter’s School (welding/brazing/sheet metal/pipework/hand tools), I was asked if I wanted to go to NDT school. After they told me what it was, I said sure.

Q. Can you tell us about your certification and training? Military? Did most of it come about as on-the-job training?
A. The Navy’s Nondestructive Testing School expanded to include UT of silver brazed joints after the loss of the USS Thresher in 1963. By the time I attended in 1970, codes, standards, specifications, mathematics, and physics were the first three weeks of training, then three weeks each for VT, PT, MT, RT, and UT. My Navy certifications were based heavily on proctored and challenging written exams and proficiency demonstrations on known defect samples. Since then, I have been to hundreds of hours of training in many topics.

Q. Do you have ASNT certification?
A. I was on the leading edge of getting ASNT NDT Level III status. Then again I was the first one to take the ACCP Professional Level III proficiency demonstration exams to prove Level II ability. The process was a visual testing hands-on practical exam with five applications over a three-hour period continuously witnessed by proctors.

Q. Describe the work you did in the Navy.
A. I reported to the USN fleet aboard a nuclear submarine tender testing repairs made on FBM submarines while on board the USS Holland (AS32). I spent three years in Rota, Spain and Charleston, South Carolina. I was certified as an NDT inspector (Level II) most of that time. At the end of my enlistment I volunteered to take the NAVSEA Nuclear Power Examiner (Level III) tests at Bettis Atomic Power Labs in Pittsburgh, Pennsylvania. After being certified in three methods, the folks at Curtiss-Wright (C-W) Nuclear, a manufacturer of nuclear submarine components, wanted to talk to me.

Q. What was the working environment like?
A. While in the Navy we worked 24 hours a day every third day and 8 to 10 hour days the other two for months in a row. Weld repairs mostly required RT and PT to be performed. But MT of hulls, UT of silver brazed joints and VT of everything was common. The tender was a floating factory. Much NDT done in the lab onboard and a short walk over a gangplank led to the submarines moored to our sides. That was our fieldwork. At C-W Nuclear it was strictly component fabrication work in a factory setting, and occasional field trips to NDT vendors for audits. One NDT lab scored very poorly after my visit and the manager quit. They offered the job to me. After a year the local nuclear utility needed an NDT project manager to supervise the NDT contracts at the power plant. I accepted their offer.

Q. Is your work focused on a particular field?
A. My focus for 30 years was military and civilian nuclear power electric generation. During that time I became an author and instructor of nondestructive evaluation (NDE) training courses for the Electric Power Research Institute (EPRI). They were working on standardizing NDE in the nuclear power electric generation industry with heavy emphasis on performance-based training and proficiency demonstration in addition to classroom theory training.
ASME Section XI, Rules for Inservice Inspection emphasized VT-1, -2, -3, and -4. The detection and sizing of intergranular stress corrosion cracking caused new UT techniques to be developed and utilized.

Q. What kind of structures did you test?
A. In addition to nuclear power electric production I worked on fossil power utilities. It was all heat transfer via piping, vessels, steam generators, pressurizers, pumps, valves, hangers, snubbers, restraint, and structural welded supports.

Q. What kind of indications were you looking for?
A. Power piping and pressure vessels required us to look for welding defects and service-induced discontinuities. The biggest challenge was differentiating between fabrication induced flaws and service induced flaws and to separate both from geometric indications. Comparing original construction RT indications to present-day UT indications was especially challenging.

Q. Do you work alone or with a crew?
A. In the Navy I was a single contributor working up to supervisor level. In the factory I was a Corporate Level III and trainer. In the nuclear power utility I was the Corporate Level III and had a staff of up to eight NDT engineers/technicians supervising the in-service inspection program with up to 30 NDE vendors at each refueling outage. Next, EPRI employed me as NDE instruction manager. I authored and taught VT and UT, and Basic instructor courses. After 12 years as an instructor in the nuclear academy mold, I was hired to start corporate wide training for a major NDT services company as the director. I assembled a staff of eight training professionals and initiated a learning management system for online training and continuing instructor-led training and development. NDT courses and certification exams were developed for over 3000 inspectors including certification exams online.

Q. What codes and/or standards must you be knowledgeable of?
A. ASME, ANSI, ISO, ASTM, MILSTD, and NAS, with a focus on aerospace, petrochem, or power industries: ASME for power piping; ANSI for processing, and mil-standards for aerospace or maritime industries. Of course, ASTM for any industry as a starting point.

Q. What innovations have you experienced in working methods?
A. During the 1980s, intergranular stress corrosion cracking was the new problem to focus on finding accurately and with heretofore unknown sensitivity. Five percent or less cracks in the root heat-affected zone was no longer just signals lost in the noise of the root geometry. Dozens of UT techniques were developed and explored. The entire UT system, personnel, equipment, procedures, and reference reflectors had to be demonstrated as accurate and dependable to increase the probability of detection.

More of Michael Allgaier’s interview can be found at: tc.asnt.org/pro/b/practionerprofile
Mike Allgaier can be reached at (201) 841-8675.