PHASED ARRAY ULTRASONIC INSPECTION OF NEW WROUGHT RAILROAD WHEEL RIMS

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SUMMARY

This paper describes the development, installation and use of phased array ultrasonic inspection systems for the evaluation of new wrought railroad wheel rims. The phased array inspection systems for wheels use conventional ultrasonic technology, but employ sophisticated electronics and computer controls to facilitate inspection of the wheel rim. Phased array technology has been successfully used for many years in medical applications, and has also been applied to other manufacturing operations, such as the production of welded steel tubing.

Additionally, the paper describes the reasons behind adoption of new phased array inspection technology for wheels including the demanding railway service environment and AAR specification changes. The theory of operation for phased arrays used in wheel inspection is reviewed, including the "steering" and "focusing" of ultrasonic beams. The many advantages of using phased array systems for inspection of new railroad wheel rims, including testing flexibility, ease of testing set-up for operators, and data collection capability, are described in the paper. Data collection software supplied by the system vendor is described, and data collected during phased array inspection of wheels are presented and discussed.

INTRODUCTION

Standard Steel, with manufacturing facilities located in Burnham and Latrobe, Pennsylvania, has produced products for the railway industry for nearly 150 years. The firm produced the first steel tires for locomotives in 1856 and currently produces wheels, axles, tires and other non-railroad related forgings. Modernization efforts have recently focused on improvements to the wheel forging and rolling operation[1] and on upgrades to axle forging equipment. The recent installation of the world's first phased array ultrasonic inspection system for wheels represents another effort designed to insure supply of the highest quality products.

THE NORTH AMERICAN RAILWAY SERVICE ENVIRONMENT

Approximately 1.3 million freight cars and 20,000 locomotives are in service in North America[2]. It is well established that the North American railway service environment is among the most demanding in the world, particularly when freight service is considered. Clearly, railway wheels are now experiencing the most challenging service environment in our history due to the following conditions:

- More common 129,700 kg (286,000 pounds) gross rail load (GRL) cars lead to higher mechanical and thermal (braking) loads for wheels.
- The dramatic increase in wheel shelling and spalling defects during the last decade.
- Larger and more frequent wheel/rail impact loads from additional tread defects.
- Improved car utilization leads to more fatigue cycles in service.
- New high-horsepower, high adhesion AC locomotives have higher tractive effort and weigh 192,800 kg (425,000 pounds).
- Passenger train speeds are increasing.

New locomotive models are very powerful (up to 6,000 HP) and there is also discussion regarding increase of the freight car allowable gross rail load to 142,900 kg (315,000 pounds). All of these changes mean that wheels will continue to be under greater loads than ever before and thus manufacturers must continue improvement efforts.

WHEEL DEFECTS AND SERVICE DATA

Much has been published in the literature regarding shelling and spalling defects on the wheel tread and the formation mechanisms of these defects. Such defects can lead to flat spots on the wheel tread and out-of-round conditions that will result in high wheel/rail impact loading. Shelling and spalling defects can, if not removed from service in a timely fashion, lead to larger fatigue cracks and wheel failures. Additionally, the costs associated with shelling and spalling defects and other wheel defects resulting from “environmental” causes (slid flats, built up tread, out-of-round, etc.) can be very large[3,4]. Since this paper is concerned with ultrasonic inspection of the wheel rim and detection of internal defects in newly manufactured wheels, a more complete review of shelling, spalling and other tread-damage related service defects will not be presented.

Shattered rim defects (AAR why made code 71), on the other hand, are defects that are directly related to internal wheel rim quality. Shattered rims are fatigue failures that initiate in service at areas of porosity or inclusions in the wheel rim and then propagate to failure. Several recent papers have described shattered rims and have provided our industry with a better understanding of how such failures occur. Five papers on shattered rims are referenced here[5,6,7,8,9], although other information has been published. Authors have described that shattered rims normally initiate approximately 12 to 20 mm (1/2 to 3/4 inches) below the tread surface at voids and porosity in cast wheels and at oxide inclusions in forged wheels. Shattered rim fatigue cracks generally propagate parallel to the tread surface and normally exhibit prominent beach marks on the fracture surfaces. Once the crack is initiated, propagation is rapid.

There has been considerable technical discussion regarding the defect size necessary to initiate a shattered rim and some authors have proposed that a discontinuity as small as one mm in diameter is sufficient to initiate a shattered rim[5,6]. Marais has analyzed cast wheel shattered rims using a local strain approach and the stress/strain concentration associated with casting porosity[5]. Lunden calculated the size of a “safe” crack length in a wheel rim to be one mm in diameter[6]. Lixian, et al. described a model for fatigue crack initiation at oxide inclusions in forged wheels[7]. Stone has provided a comprehensive review of shattered rim wheels complete with many references[8]. Finally, a recent paper by Stone and Dahlman presented micrographic evidence that a derailment-causing shattered rim initiated at a cast wheel void of only 0.64-mm (0.025 inches) in diameter[9].

Figure 1 shows the number of shattered rims (AAR why made code 71) removed and reported as part of AAR Car Repair Billing (CRB) data during the period 1980 through 1999. Note that although the general trend is clearly towards fewer shattered rims since 1980, there has been a recent increase in the number of wheels removed for this defect. To maintain perspective however, it must be noted that shattered rims are an infrequent mode of wheel failure. Shattered rims represented just 301 AAR CRB wheel removals out of the 511,299 total wheels (0.058% of total) removed in 1999.

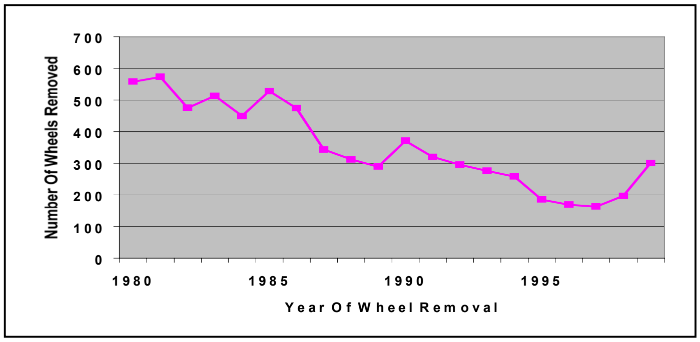


Figure 1. AAR CRB shattered rim data, 1980-1999.

Wheel changeouts reported as part of AAR CRB data basically represent only those repairs that are made as “foreign” repairs between railroads, or involving railroad repairs to privately owned cars. Thus, since railroad “system” repairs and non-railroad contract shop repairs are not included in the data, CRB repairs are estimated to be only 40% of all North American wheel removals. If all wheel repairs in North America were included in a database, it is likely that the number of recorded shattered rims would be significantly greater. Another important factor regarding CRB data is the wheel defect reporting issue, where the incorrect wheel removal code could be associated with a defective wheel. It is likely that many “cracked rims” (why made code 68) are actually shattered rims that have not been reported properly. A more complete discussion of issues surrounding 1999 AAR CRB wheel removals is found in a paper presented at the 2000 Railway Wheel Manufacturers’ Engineering Committee (RWMEC) Conference[4].

The AAR also keeps records for MD-115 forms that have been submitted from the field. These documents report wheels that have failed in service due to various defects. A recent paper on shattered rims presented MD-115 wheel failure data in graphical form and showed that most shattered rims occur when wheels are relatively new[8], with a greater percent remaining rim thickness. The author stated that “most shattered rims are infant mortality failures caused by a critical inclusion or void that is of sufficient size and location to initiate early fatigue growth." Also noted in the data was another grouping of shattered rim failures that occurred for wheels with greatly reduced rim thickness near the condemning limit. Investigators at a major wheel manufacturer have suggested that these late-life shattered rim fatigue cracks are the result of service related wheel impact damage that is not detected during wheel re-profiling[10]. Wheels are subsequently returned to service with cracking that later fully develops into a shattered rim failure. These researchers have generated failures similar to shattered rims on a dynamometer by increasing the mechanical load to significantly higher levels than normal wheel loadings. It is quite possible that shattered rims are influenced by wheel dynamic impact loading resulting from shells/spalls, built-up-tread, slid flat wheels and out-of-round wheels. However, this relationship is not well understood at this time and further research has started[11].

The Federal Railroad Administration (FRA) maintains a website database that contains statistics on train accidents within the United States. The number of U. S. train derailments caused by broken wheel rims remains low, although such derailments can be quite dangerous and expensive since wheels can fail during train operations at high speed. Figure 2 shows the number of train derailments caused by broken wheel rims during the period 1985 through August 2000[12].

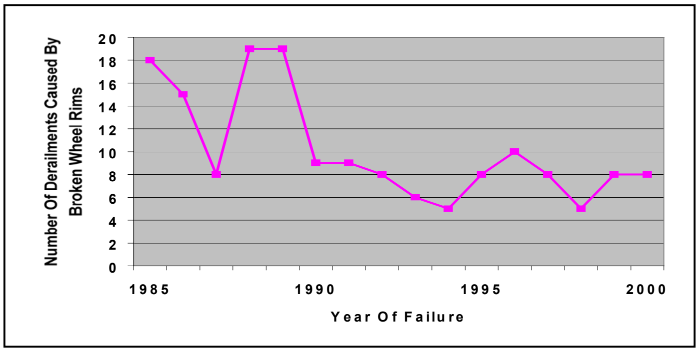


Figure 2. Number of broken wheel rims that caused derailments, from the FRA database, 1985 through August 2000.

Note that the number of wheel related derailments has shown a general downward trend over the years. This is surely due to the removal of inferior straight plate wheels and untreated wheels from service and to the many production improvements made by wheel manufacturers.

Several major wheel-related derailments on railroads in the Western United States also have led to increased scrutiny for wheels within the last few years. Recent notable problems with certain wheels in freight service have affected the confidence of users. As a result of the perception that wheels were causing a greater than acceptable number of problems, the AAR began to review the ultrasonic inspection specification for new wheels.

AAR ULTRASONIC TESTING SPECIFICATION CHANGES

In October 2000 the AAR adopted a completed, revised specification for the ultrasonic testing of newly manufactured wheel rims. However, tightening of the ultrasonic rejection standard was previously instituted in July of 1999. The old AAR ultrasonic specification had remained essentially unchanged since its adoption in the late 1960's. Manufacturers participated fully in developing the new specification, which mandates that ultrasonic scanning of the rim is conducted in the radial (from the tread surface) and axial (from the rim face) directions. Major changes to the specification are summarized as follows:

- There is now a requirement to use an automated scanning system for wheel rim inspection.
- A distance amplitude correction is included for both radial and axial scans.
- The indication rejection criteria were tightened from 100% the response of a 3.18-mm (1/8 inch) flat bottom hole to 50% of the response from a 1/8 inch flat bottom hole.
- Additional holes must be present in the calibration wheel to improve volumetric coverage of the ultrasonic scan.

THE NEED FOR AN IMPROVED WHEEL ULTRASONIC INSPECTION SYSTEM

With increased railway service demands, the need for greater wheel quality than ever before and an impending tightening of the AAR specification, Standard Steel began to investigate improved ultrasonic inspection systems in 1998. The ultrasonic immersion inspection system previously used by Standard Steel was an analog one and involved the use of two large "paintbrush" transducers that have a crystal length greater than the crystal width. This type of large, single element, 2.5 MHz transducer provides for a wide area of inspection, allows for fast, automated inspection and is well suited for immersion inspection.

Although the old wheel rim inspection method was found to be adequate and in compliance with AAR requirements at the time, there was room for inspection improvement. This was true with regard to axial resolution (the ability to separate reflectors that are close together at different depths) and lateral resolution (the ability to separate two or more flaws at the same depth) of near surface and smaller indications. A higher frequency (shorter pulse length) transducer provides for improved axial resolution. A larger transducer diameter provides for less lateral resolution and has a longer near field zone. Improved sensitivity, defined as a test system's response to a given size reflector at a given distance, improves with higher transducer frequency. Further, due to the wide variety of wheel rim design sizes produced by Standard Steel, it was necessary for the inspection system operator to manually "peak up" the ultrasonic signal each time a new wheel type was to be inspected. Finally, there was a desire to increase volumetric inspection coverage of the rim, decrease the signal to noise ratio, and use a digital system with data collection and storage capability.

BASIC THEORY OF ULTRASONICS

Ultrasonic inspection of industrial components utilizes high frequency sound to detect material discontinuities within the part. The ultrasound instrument initiates the process by generating an electrical signal which is sent to the transducer. The ultrasound transducer converts the electrical signal generated by the instrumentation into an acoustic signal which is then coupled into the piece being tested. The sound will propagate into the part much like the propagation of a light beam from a flashlight into a transparent material. When the sound encounters a material discontinuity, such as a crack, or porosity, or the back surface of the component, some of the sound is reflected. When the reflected sound returns to the transducer, it will be converted back into an electrical signal and recorded by the instrument as shown below in Figure 3.

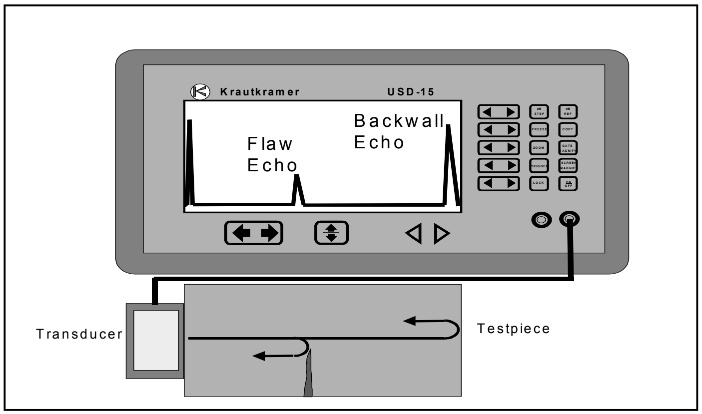


Figure 3. Transmission, reflection and detection of ultrasound by an inspection instrument.

Knowing the propagation velocity in the inspected material, the distance to the reflector can be calculated:

$$D = \frac{(c * t)}{2}$$

Equation 1

where

D is distance
C is acoustic velocity of propagation
T is time of propagation

The division by 2 accounts for the fact that the ultrasonic pulse has traversed the distance to the reflector twice.

UTRASOUND ARRAY TRANSDUCERS

The technique described in the previous section enables one to locate an internal flaw provided it lies close to the sound beam emanated from the transducer. To interrogate an entire component, the probe must be scanned so that all internal locations in the component are accessed by the sound field. Early in the history of ultrasonic inspection manual scanning of the transducer was the only alternative. The technique was effective but also slow, and total coverage of the part was uncertain. But in the early 1970's, linear array technology was developed that enabled some geometric shapes to be inspected much more rapidly.

A linear array transducer is a group of many small rectangular contiguous transducers in a single housing. A typical assembly might comprise 128 element over 76 to 102 mm (3 or 4 inches). Using multiplexing circuitry a group of four or more adjacent elements (for example elements one to four) are connected to the ultrasound instrument. This group emits a sound field much like a conventional single element transducer and information about flaws in the testpiece lying along the axis of the array group can be gathered. The multiplexing circuitry can then change the connections to elements two through five, effectively moving the active group by one element. Information along this path is gathered and the multiplexor is indexed again. This process is continued until the active group, or virtual probe, is electronically scanned along the entire length of the linear array. This scanning can occur very rapidly, but is sometimes limited by the time necessary to receive a signal. For example, when testing a thick material it is necessary to wait for possible echoes from the most distant material. In testing thinner sections less time is required and the array can be scanned at a higher rate.

Electronic scanning using linear arrays dramatically reduced inspection times for inspection situations which required only transducer scans without focal changes or changes in sound beam direction. Inspection of plate or strip material is a good example. Meyer, Miller, and Carodiskey[13] describe this application in detail.

Unfortunately, many inspection situations are not well suited for linear array systems. A phased array transducer is a 1-D rectangular group of individual elements, each having its own pulser and receiver circuitry. All elements are connected to, and controlled by, a computerized ultrasound system that is able to activate each element independently. By timing, or phasing the individual elements appropriately, the system can mimic a wide variety of transducer designs. For example, a cylindrically converging wavefront can be created as shown in Figure 4.

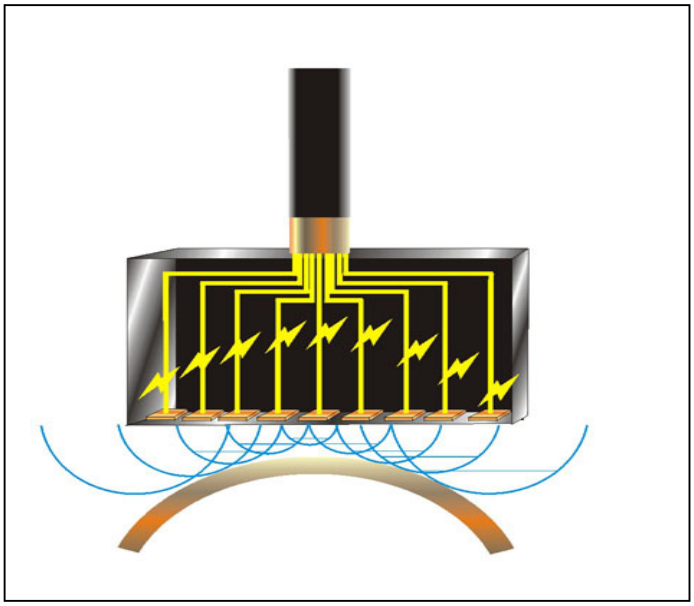


Figure 4. Electronic phasing used to generate a focused sound field.

This is analogous to the phase delays caused by the mechanical lens placed on the front of a single-element transducer discussed above. Using a different phase pattern, a different focal point can be achieved. It is for this reason that phased arrays are sometimes called "electronic lenses." Using a linear phase delay, the system can also steer the sound beam off the axis of the transducer as shown in Figure 5.

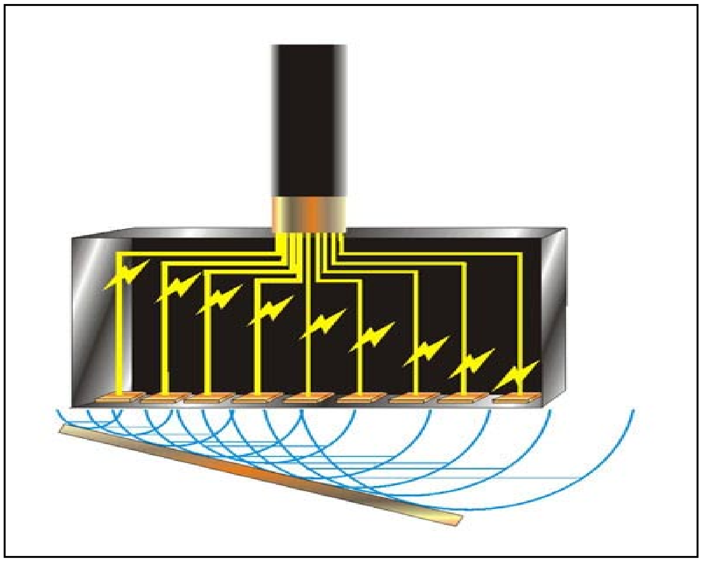


Figure 5. Electronic phasing used to steer a sound field.

Naturally, these patterns can be combined to steer and focus simultaneously. Other phase delay patterns permit interrogation of many sections of the testpiece with a properly designed phased array transducer.

THEORY OF PHASED ARRAY OPERATION

Before designing a phased array transducer for a specific application, it is helpful to understand the sound field radiated by a single-element transducer. The sound field characteristics of a single-element transducer can be calculated[14] knowing:

- The size and shape of the radiating element
- The emitted pulse characteristics
- The characteristics of the propagating medium

Nearfield of a Transducer

Let's consider a circular transducer radiating a monochromatic signal. If a small reflector is moved throughout the insonified material so that the signal at each point is reflected back to the transducer, the echo can be detected and recorded. The resultant field plot is found to be a cylindrical volume immediately in front of the source followed by a diverging conical section as shown in Figure 6. The cylindrical section is a region of large amplitude variations caused by the interference of the signal from various locations on the source. This region is called the *Nearfield*. The length of the *Nearfield* (N) can be calculated:

$$N = \frac{D^2 - \lambda^2}{4\lambda}$$

Equation 2

where

D is the diameter of the source

λ is the wavelength of the radiated signal

In many situations, the diameter of the source is larger that the radiated wavelength, therefore λ^2 can be neglected when compared to D^2 and the *Nearfield* length can be approximated

$$N = \frac{D^2}{4\lambda}$$

Equation 3

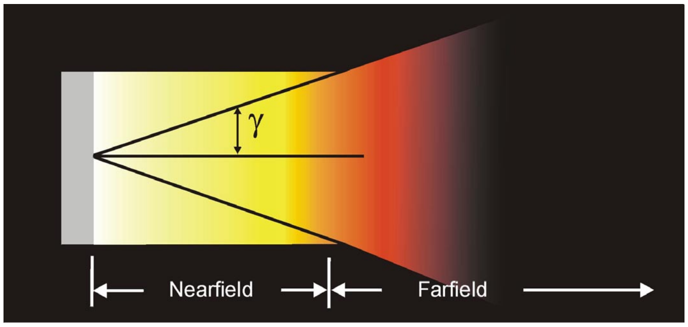
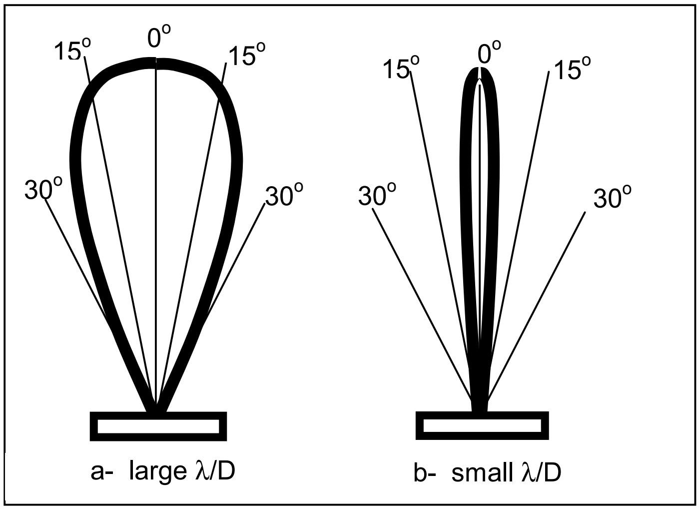


Figure 6. Sound field emitted by a transducer.

The conical region beyond the *Nearfield* is less turbulent because the path length differences to any point on the source are less than λ and, therefore, there can be little destructive interference. This region is called the *Farfield* of the transducer and extends from the end of the *Nearfield* to infinity.

Sound Field Divergence

The rate at which the energy in this region diverges is also a function of the source diameter (D) and the radiated wavelength (λ). The highest amplitude signal occurs on the axis of the transducer and signal amplitude decreases as the angular displacement from the axis is increased as shown in Figure 7.



a- large λ/D b- small λ/D

Figure 7. Effect of λ/D ratio on sound field divergence.

Although the signal is radiated into the entire material volume, most energy is included in this conical *farfield* region. We arbitrarily define the lateral limits of this cone as the angle at which the signal amplitude is reduced by 6 dB relative to the axial amplitude. Other reduction levels could be used but –6 dB is an accepted guideline.

The angle (γ) at which the signal amplitude is reduced by 6 dB can be calculated

$$\gamma = \sin^{-1}(0.7 * \frac{\lambda}{D}) \qquad \text{Equation 4}$$

It can be seen that in situations in which λ is large compared to D, the divergence angle can be large. This makes location of the reflector more difficult because the sound field is large. For this reason, most inspection codes specify ultrasound transducers having small divergence angles so that the reflector can be located more precisely. This can be accomplished using at least two techniques. First, the divergence angle can be reduced by reducing the λ/D ratio in equation 4 above. Higher frequencies producing smaller wavelengths, and/or larger diameters will accomplish this objective. The second technique is focusing the ultrasound source itself.

Focused Transducers

As indicated earlier, the sound field characteristics are the result of phase interference of signals from all points on the source. The equations and discussions above assume that the source is circular and flat. Changing the curvature of the source, however, changes the relative phase of contributions from points on the source and, hence, changes the field pattern. As the degree of concavity of the source is increased, the *Nearfield* changes from a cylindrical region to a converging conical region and the nearfield length is reduced. Focusing permits very small beamwidths to be achieved but only in the region of the focal point as shown in Figure 8.

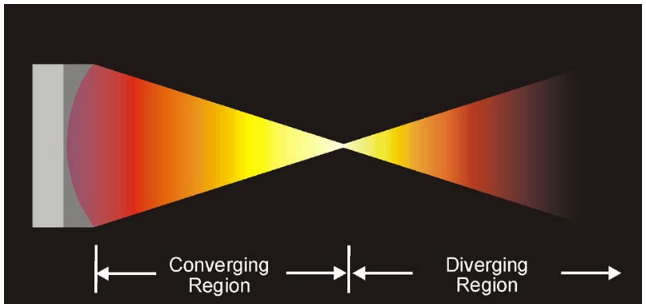


Figure 8. Schematic showing the sound field of a focused transducer.

Unfortunately, the divergence angle beyond the focal point of a focused transducer increases often-making reflector detection or location difficult beyond the focal point. Because the nearfield length is diffraction limited, it is not possible to focus beyond the nearfield length of the source.

Transducer Design for Specific Applications

The purpose of the discussion so far has been to convey the idea that, given a particular test situation, one can choose an appropriate transducer size, frequency, and focal characteristic such that good reflector detectability exists in a region where the reflector is expected. Reflectors far from this region may be difficult to detect and a second transducer design may be necessary to interrogate the second region. This concept of using multiple transducers in an inspection is often used. Several transducers, each having different sound field characteristics and orientations are used to interrogate various regions of the testpiece and the results of these scans are assembled into an overall evaluation.

If there are several different testpieces to be inspected, many different sets of transducers may be required. Furthermore, this hardware change, along with the calibration verification is likely to be time consuming.

Phased Arrays Are More Versatile

It should be apparent that a system in which the sound field can be scanned, steered, and focused electronically is much more versatile than a conventional system. Several different sound field configurations can be stored in system memory and recalled as necessary. As a manufacturing line is changed from one type part to another, the inspection system can reconfigure itself very quickly to inspect the new part. If necessary, it is even possible to change configurations on consecutive pulse cycles.

Array System Performance

For railroad wheel inspection we have developed a phased array test system that uses two array transducers each having 128 elements. The two arrays are arranged so that one interrogates the wheel rim from the wheel tread and the other interrogates it from the back rim face, as shown in Figure 9. Using inspection from two directions ensures that defects anywhere in the rim region will be detected, regardless of orientation.

The ultrasonic frequency is 5 MHz, and the “virtual probe” is a group of 16 elements, 16 mm x 16 mm. This configuration provides reliable detection to the current AAR specification. Future requirements can be met by set-up changes or changes in the array configuration.

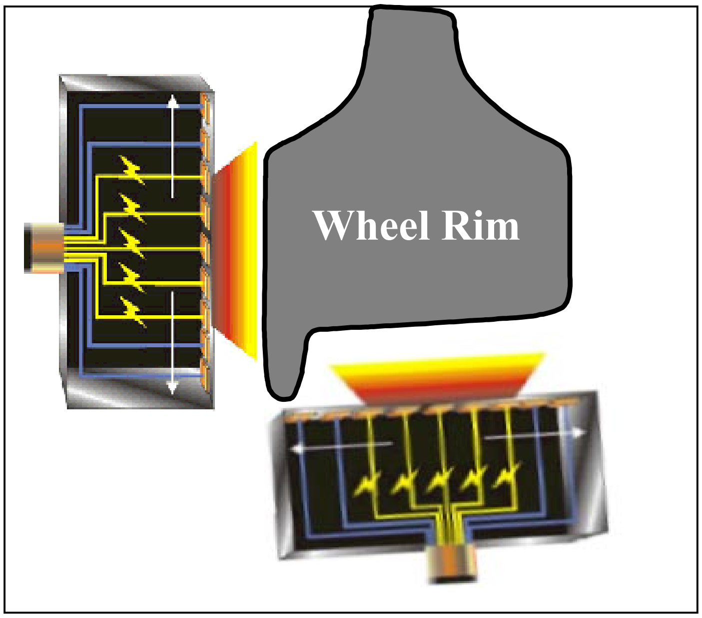


Figure 9. Phased array system for railroad wheel inspection.

THE STANDARD STEEL PHASED ARRAY SYSTEMS FOR RAILROAD WHEELS

Currently Standard Steel has three phased array, immersion ultrasonic inspection systems for wrought wheels installed at the Burnham, PA, plant. These phased array systems are the first such systems in the world used to evaluate new wheels on a production basis. The first two systems were installed in July, 1999.

All wheel designs produced by Standard are tested using one of the new systems. In general, wrought wheel producers manufacture a greater variety of wheel designs due to their involvement in freight, locomotive and passenger/transit market segments. Each different wheel design requires the initial entry of all wheel rim dimensions into the phased array system. This information, known as a “data set,” provides the phased array system with the ultrasonic scanning boundaries for each type of wheel rim. This helps to insure that the maximum volumetric coverage is obtained during ultrasonic testing and insures that geometric differences do not create false indication alarms. Variations in tread profile, rim thickness, etc., could lead to false rejections if the system computer is scanning a different wheel rim design than the wheel physically being tested. Therefore, before a given group of wheels is inspected, the system operator inputs the correct wheel design designation (for example, H36) and the computer then performs scanning as instructed. The correct number and location of individual ultrasonic transducers is activated depending on the wheel design being tested.

One inspection line has automated handling equipment associated with it while the other two inspection locations have manual handling. When the wheel is inserted in the immersion tank for scanning, a mechanical roller contacts the tread and rotates the wheel through 360 degrees. Two large ultrasonic probes, each containing 128 individual transducers (all 5 MHz) in 16 groups (256 total transducers), are large enough to test all possible wheel designs and perform the inspection in both the axial and radial directions. The axial scan is performed from the back rim face to improve volumetric coverage and avoid the front rim face/tread radius and the witness groove.

Due to the nature of the wrought wheel production process where any discontinuities present in the rim are “flattened” in the 10,000-ton forging press and the 4,000-ton dishing press, the axial orientation is normally where indications are detected. Few indications have ever been found with ultrasonic scanning in the radial direction, but such testing is performed due to the AAR specification requirement. The phased array systems have the capability to “steer” and “focus” ultrasonic beams within the wheel rim and also can perform multiple scans. If a rejectable indication is found during inspection, an automated alarm sounds to notify the operator, as required by the AAR specification.

Each phased array system has water and dust proof cabinets that house the computer and protect it from the harsh manufacturing shop environment. Key pads and bar code label wands are provided for operators to input wheel design information. All three systems have tiered security access to prevent unauthorized changing of test parameters, data sets, etc. The cabinets are locked, computer changes require a password and only the ASNT Level III Supervisor, and members of management, or their designated representative, are permitted to modify test parameters.

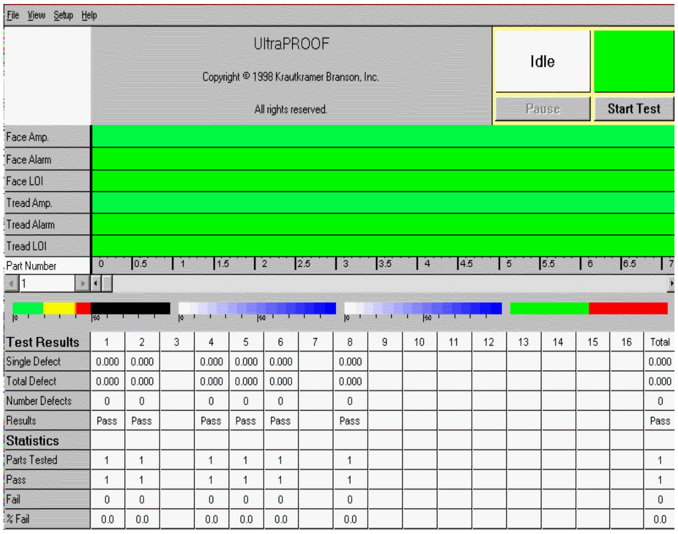
The phased array systems have proven their worth in the testing of railway wheels and are a complete success. Improved rim volumetric coverage, improved resolution and greater sensitivity all provide for a higher quality evaluation of the rim than was obtained previously using older paintbrush transducers. The new inspection systems are more flexible with regard to testing changes, have eliminated the need for operator manual transducer adjustments, and allow for computer interface capability. Ultrasonic scan information now can be saved and data can be analyzed. Inspection is more consistent and significantly more information regarding wheel rim quality is now available. Finally, system parameters are easily changed to account for any specification requirements.

ULTRAPROOF SCAN RECORDING SOFTWARE

The phased array systems are equipped with Ultraproof data recording software that allows for saving the results of ultrasonic inspections. Ultraproof provides an “electronic strip chart” of data for a given rotational scan of the wheel. Such electronic strip charts are presented for the rim face (axial) scan and the tread (radial) scan, and different colors are used to identify the various amplitudes of ultrasonic indications.

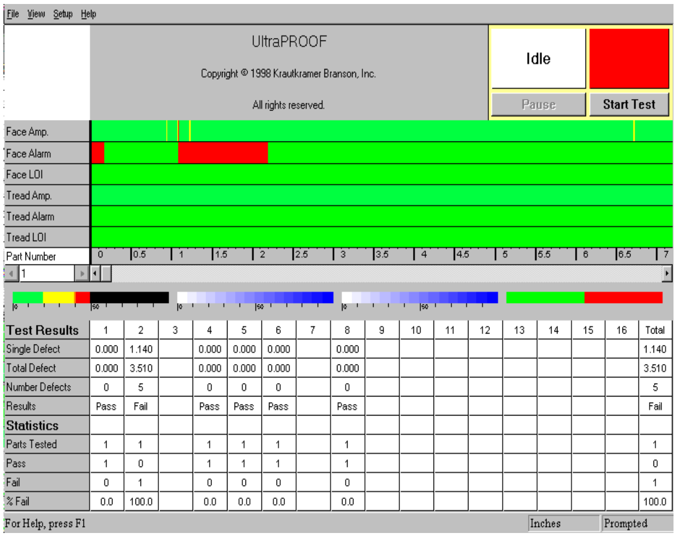
A green color means that there are no indications greater than the rejectable indication amplitude (wheel OK), whereas a red color means that an indication has broken the rejectable gate level (wheel failed). Other colors can be used to show those indications that are less than rejectable yet greater than some intermediate level. The relative size of detected indications is shown on the colored bands. The number of indications detected in the given wheel rim is shown below the strip chart data presentation, along with statistics for parts tested.

An example of an Ultraproof data presentation screen for a passing wheel test (all green bands) is shown in Figure 10. There are no indications noted on the face amplitude, face alarm, tread amplitude or tread alarm bands of the data presentation. Figure 11 shows test results for a failed wheel (green and red bands). Note that rejectable indications were found while testing in the axial direction, across the rim section. These results are shown on the face amplitude band where a thin line of color change has been noted and on the face alarm where a longer, darker (red) band is seen.



Test Results	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Single Defect	0.000	0.000		0.000	0.000	0.000		0.000									0.000
Total Defect	0.000	0.000		0.000	0.000	0.000		0.000									0.000
Number Defects	0	0		0	0	0		0									0
Results	Pass	Pass		Pass	Pass	Pass		Pass									Pass
Statistics																	
Parts Tested	1	1		1	1	1		1									1
Pass	1	1		1	1	1		1									1
Fail	0	0		0	0	0		0									0
% Fail	0.0	0.0		0.0	0.0	0.0		0.0									0.0

Figure 10. Ultraproof trace for a good wheel.



Test Results	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Single Defect	0.000	1.140		0.000	0.000	0.000		0.000									1.140
Total Defect	0.000	3.510		0.000	0.000	0.000		0.000									3.510
Number Defects	0	5		0	0	0		0									5
Results	Pass	Fail		Pass	Pass	Pass		Pass									Fail
Statistics																	
Parts Tested	1	1		1	1	1		1									1
Pass	1	0		1	1	1		1									0
Fail	0	1		0	0	0		0									1
% Fail	0.0	100.0		0.0	0.0	0.0		0.0									100.0

Figure 11. Ultraproof trace for a rejected wheel.

DISCUSSION - FUTURE ISSUES FOR WHEEL ULTRASONIC TESTING

As previously reviewed, the AAR ultrasonic specification was recently updated and the rejection criteria were tightened. A rejection standard of 50% of the response from a 3.18 mm (1/8 inch) diameter flat bottom hole means that the rejectable indication diameter now is 0.088 inches, or slightly larger than two mm. The current rejection standard is two times tighter than the previous rejection standard due to the area effect of flat bottom holes. It is possible that further tightening of the rejection criteria will take place in the future.

Further increases in wheel service loading will have a major effect on the direction of future specification changes. If the allowable gross rail load for freight cars increases beyond the current 129,700 kg (286,000 pounds) maximum level, and if locomotive horsepower and adhesion levels continue to escalate, it is likely that there will be additional wheel failures. Perhaps future wheel ultrasonic specifications will be based upon wheel loading levels, with tighter specification requirements for more demanding service applications. The authors realize that there will be AAR field wheel replacement issues for those wheels inspected to different rejection standards. However, the ultrasonic quality needed for wheels on a coal car loaded to 142,900 kg (315,000 pounds) gross rail load is clearly different than that necessary for rail equipment that is not in demanding service.

Currently each wheel manufacturer produces calibration wheels in accordance with the AAR specification to verify that their ultrasonic inspection system can successfully identify rejectable defects. Given the high level of scrutiny on wheel issues, the wide variety of ultrasonic test equipment used by wheel manufacturers, and the desire of manufacturers to produce the best quality product, perhaps it is time for “round robin” calibration wheels. These wheels could be made by one source as identical calibration standards and could be used to certify the ultrasonic system of each AAR approved wheel manufacturer.

Recently microcleanliness testing of wheels was started by a major railroad to improve wheel quality and reduce the incidence of shattered rims. Such testing is outlined in a recent paper that discussed the effect of discontinuity size on shattered rims[9]. Six metallographic samples are removed from the wheel rim at a depth of 12 mm (1/2 inch) below the tread surface, are polished and microcleanliness measurements are made using ASTM E-1245.

We believe that a better method to evaluate the cleanliness and suitability for service of a wheel rim is to use ultrasonic testing to inspect the volume of the rim. Perhaps some measure of ultrasonic cleanliness should be used in lieu of metallographic examination since the latter testing evaluates only two-dimensional planes of the wheel rim. Phased array inspection systems, with software provided by the manufacturer, are well suited for such ultrasonic cleanliness measurements.

Since a great deal of concern has been placed upon shattered rim failures, perhaps future ultrasonic specifications should consider a focused inspection if a particular area of the rim can be defined as an area of concern. Such an inspection could be performed in addition to the normal ultrasonic inspection and could more tightly inspect a defined region of the wheel rim.

Finally, additional work should be conducted to better understand the effect of impact loadings on shattered rim initiation, and on detection of cracks in wheels after reprofiling. Impacts from shells/spalls, slid flats, built up tread, etc., may play an important role in wheel fatigue life. Also, an increase in wheel hardness may have benefits for improved fatigue resistance.

CONCLUDING REMARKS

With the increased demands of railway service it is critically important that wheel manufacturers produce a product with the best possible quality. Manufacturers have no control over the severe service environment experienced by railway wheels and thus must insure that wheel inspections are conducted using the best possible methods and technology. Standard Steel identified the need for improved ultrasonic inspection technology and selected Krautkramer-Branson’s state-of the-art phased array ultrasonic inspection systems for purchase and installation. The flexibility of the inspection systems will insure that high-quality ultrasonic inspection of new wheel rims will occur for many years to come

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