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# Phased Array Ultrasonic Testing of Wheel Samples

Kerry Jones and Lucas Welander

**Summary**

Ultrasonic testing of railroad wheels is used to detect flaws during manufacturing and sometimes while wheels are in service. Improvements in steel making technology result in cleaner steels, with fewer and finer flaws present. In order to inspect these cleaner wheel steels, advanced nondestructive methods must be used

Transportation Technology Center, Inc. contracted with EWI, a North American engineering and technology organization, to determine whether current technology would allow detection of flaws considerably smaller than those currently required under standards of the Association of American Railroads.

Several configurations of phased array probes were used to examine wheel section samples. A phased array probe provided the best results; this optimized probe gave the smallest flaw sizes and best defect resolution. Most manufacturers use automated phased array ultrasonic testing to detect flaws. With this method, more accurate information can be obtained about the location and size of individual flaws.

More work is needed in this area. Current testing was not conclusive enough to determine a practical lower detection limit. Further analysis of the wheel section samples by radiography and ultrasonic testing will be performed later this year to verify flaw sizes and to calibrate the phased array ultrasonic transducer. In addition, similar testing on cast wheels will be performed.

Please contact **Kerry Jones** at **(719) 584-0592** with questions or concerns regarding this *Technology Digest.* E-mail: kerry_jones@aar.com.

## INTRODUCTION

As part of the Association of American Railroads (AAR) Strategic Research Initiatives Program titled "Strategies to Prevent Wheel Failures," Transportation Technology Center, Inc. (TTCI) conducted trial ultrasonic testing of railroad wheel samples using phased array probes. The program was performed to compare a reduction in the minimum detectable flaw size to current industry methods. EWI used several phased array probes in earlier testing for TTCI, and an optimized matrix phased array probe was designed and used for this latest evaluation.

## BACKGROUND

Most wheel manufacturers use phased array ultrasonic testing to inspect new wheels according to AAR standards.[1] The equipment is calibrated to a flat-bottomed hole of known size before the wheel is tested. Flaw signals detected during inspection are compared with the signal corresponding to the calibration hole size. If the detected flaw is too large, the wheel is rejected.

During 2012–2014, TTCI contracted with EWI to evaluate several ultrasonic probe designs and types, such as conventional, linear phased array, and matrix phased array. TTCI furnished five wheel section samples for immersion testing in water. These tests used many parameters such as beam steering, depth focusing, frequency, and element size. Results were used to design an optimized probe, which would reduce the minimum detectable and measureable flaw sizes. Figure 1 shows an example of a C-scan of a 0.031-inch-diameter flat bottom calibration hole using a 5 MHz, 8 by 8 phased array probe.

## TEST PROCEDURE

Based on results from EWI's previous work in 2012 and 2013, an optimized matrix phased array transducer was designed and built. This probe was a two-dimensional array, defined as having equal numbers of elements in the x and y directions. It produced a 7.5 MHz signal in an 8 by 8 square array (see Figure 2). The wheel samples were tested using the optimized probe. The samples were water immersion tested from the back of the flange, as Figure 3 shows. According to EWI, a 0.031-inch-diameter flat bottom hole was used in this testing for a calibration standard.

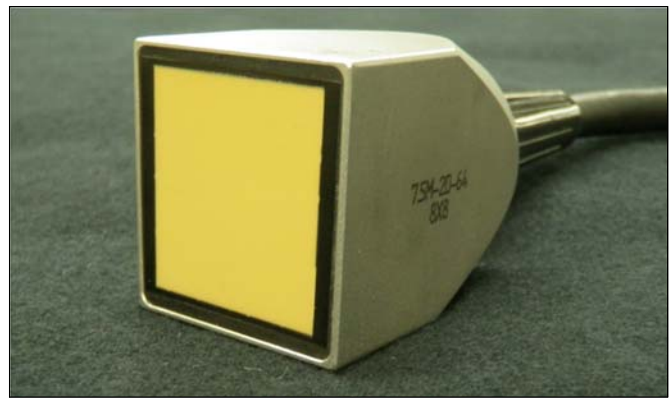


**Figure 2. Optimized 7.5 MHz, 8 by 8 Matrix Phased Array Probe**

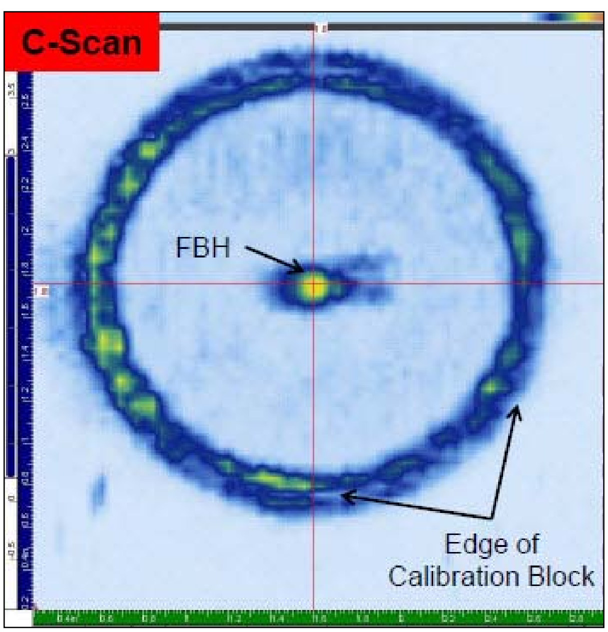


**Figure 1. C-scan of Flat Bottom 0.031-inch-diameter Calibration Hole using 5 MHz Probe**

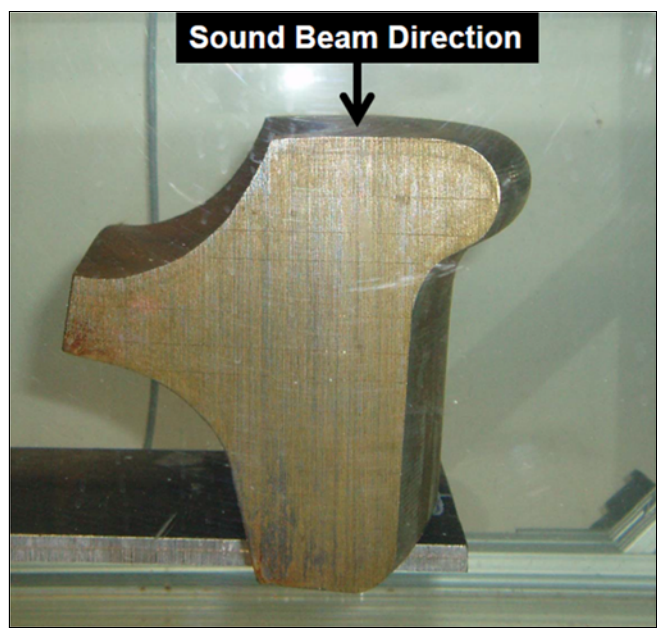


**Figure 3. Orientation of Wheel Sample and Sound Beam**

## RESULTS

The size measurements of the flat-bottom calibration holes showed improvement from EWI's previous research with other transducer configurations and were closer to the known sizes of these calibration holes (see Table 1). The measured flaw sizes also decreased compared to the previous parameters tested.

Figure 4 shows a C-scan of one of the wheel samples. The flaws are indicated by the round, blue areas. The yellow and red areas indicate larger flaws. The locations and dimensions of the flaws were measured and recorded.

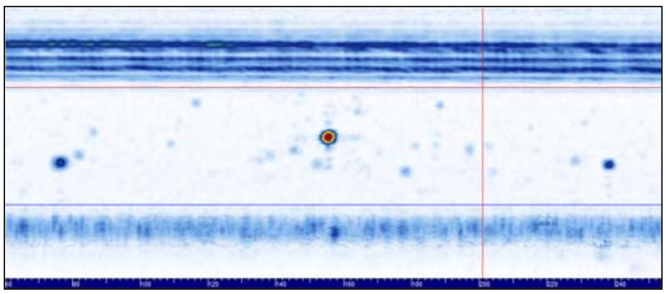

**Figure 4. C-scan of Wheel Sample using Optimized Probe**

The optimized 7.5 MHz probe reduced the minimum measurable flaw size compared to the 5 MHz probe, as Table 1 shows. The minimum measureable flaw size was reduced by 34 percent and the detection limit was reduced by 44 percent, according to these laboratory tests.

**Table 1. Measurement and Detection Limits For Matrix Phased Array Transducers**

| | 5 MHz Probe | 7.5 MHz Probe |
|---|---|---|
| | Flaw/Hole Dimension (inch) | |
| **0.031-inch Flat Bottom Calibration Hole** | 0.160 | 0.059 |
| **Minimum Measurable Flaw Size, inches** | 0.047 | 0.031 |
| **Theoretical Minimum Detection Limit, inches** | 0.023 | 0.016 |

Figure 5 shows A-, B-, and C-scans of a 0.031-inch-diameter calibration hole. According to EWI, the measured size of this flat-bottom hole is still about twice its actual size, but it is 63 percent smaller than the measured size obtained by EWI in earlier testing for TTCI with 5 MHz probes.

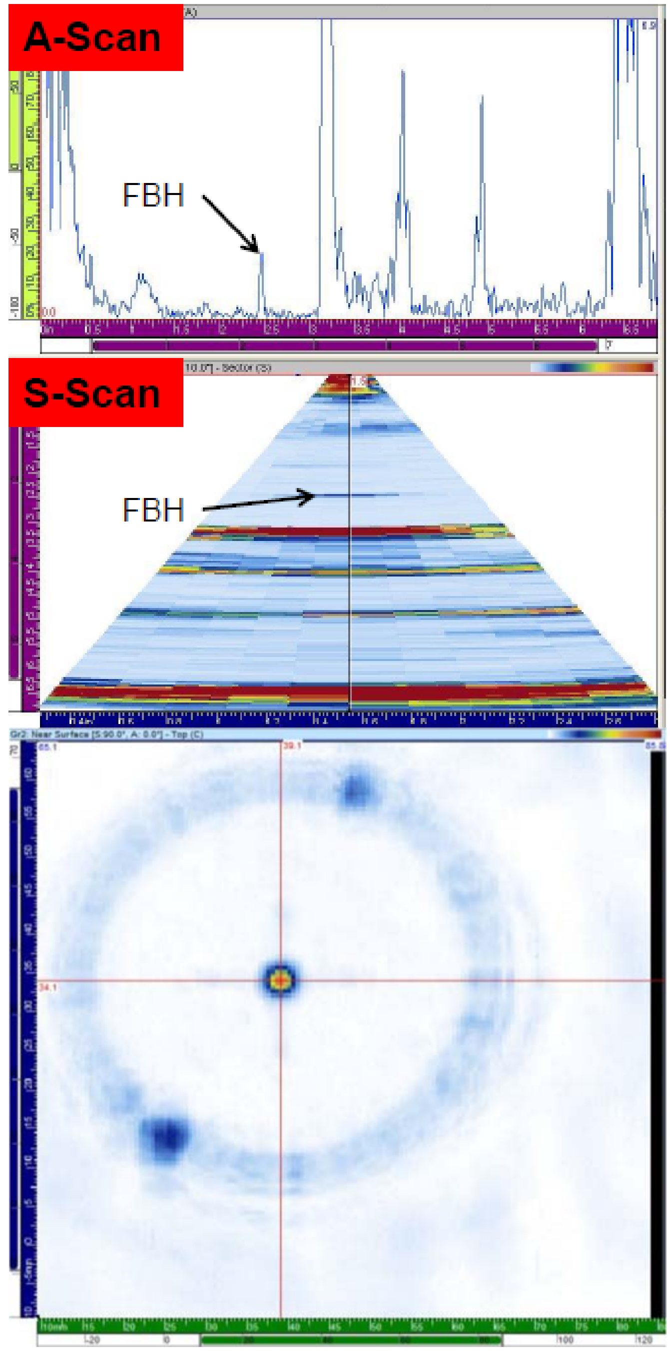


**Figure 5. A, B, and C Scans of 0.031-inch Flat Bottom Calibration Hole at 1.0-inch Depth**

## Way Forward

Before defect size guidelines can be created, further research must be done. Since the actual size and shape of flaws are not known, a test will be performed later this year. To gain knowledge of the distribution of wheel flaw shapes and sizes, wheel samples will be cut with a band saw at specific intervals near the ultrasonically detected flaws to determine the actual flaw sizes. After each slice, the flaw size will be examined ultrasonically and radiographically. This slicing method will get very near to the defects, and some may be visible to perform a physical size measurement. The measured flaw size for each method at each distance will be recorded and any relationship will be analyzed. This will serve as a type of verification or correction of the flaw sizes obtained during this research. This study looked only at wrought wheels. To examine multiple manufacturing processes, cast wheel sections, some with defects near the condemnable limit, will be obtained and tested.

Based on the principles of ultrasonic analysis, it is theoretically possible to use a 10 MHz transducer for wheel samples. This would result in the resolution of even smaller flaws and would still have adequate energy for full inspection of the wheel. Further study is needed to determine whether higher frequencies would provide the needed detection capabilities to examine the entire wheel.

## CONCLUSION

The optimized 7.5-MHz transducer showed an almost 35 percent decrease in measureable flaw size compared to the 5-MHz transducer using a 0.031-inch-diameter flat-bottomed hole as calibration. The measured size of the 0.031-inch-diameter flat-bottom hole using the optimized probe decreased 63 percent compared to the measurement of the same hole with the 5 MHz probe. This reported size was still twice as large as the actual size. More work is needed before reliable flaw size guidelines can be created.

Verification of the actual flaw sizes of the wheel samples is underway. This will be done by removing material slices parallel to the front rim face of the wheel, then using radiography and ultrasonic testing to measure flaws. This process will be done repeatedly, with cuts made at specific distances from flaws. This will provide more precise information of how flaw size varies with depth. In addition, samples of cast wheels will be obtained and will undergo the same testing as the wrought wheels to determine whether differences exist between the two types of manufacturing processes.

After the verification and the cast wheel testing are complete, enough information should be available to create ultrasonic testing guidelines for both new and remachined wheels.

More research may be needed to determine whether this, or higher, frequency transducers would provide adequate detection for full inspection of the wheel.

## REFERENCES

1. Association of American Railroads. 2011. *Manual of Standards and Recommended Practices*, Section G, Wheels and Axles, “Specification M-107/M-208: Wheels, Carbon Steel.” Washington, D.C.