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Rail Defect Locating and Sizing Using Phased Array

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Key Findings:

- A method to decode off-board phased array data has been developed with the objective of accurately locating head defects for removal by the process of rail head repair welds.
- Accuracy of ±1 inch is required to remove defects during the rail head repair weld process.
- Defect location is determined relative to a datum in the PAUT data.
- GPS coordinates identify location of the datum (bolt hole, rail end, weld), which must be identified by the repair crew.
- A distance value determined from encoder information in the phased array data provides accurate distance from the known datum (±1/2 inch).
- Final precision of locating the defect will depend on the distance of the defect from the datum and the measurement technique used to make the measurement.

As a cooperative project between the Association of American Railroads' (AAR) Strategic Research Initiative (SRI) program and the Federal Railroad Administration (FRA), Transportation Technology Center, Inc. (TTCI) has been studying the capability of locating and sizing internal defects in rail using phased array ultrasound technology (PAUT). TTCI developed a phased array rail inspection prototype for detecting rail defects in track.

This *Technology Digest* presents the methods to locate and size defects using PAUT data. The goal is to determine the capability of PAUT to precisely locate defects in the head of the rail for repair. The process of extracting and processing phased array off-board data, as well as identifying rail head defect features using A-Scan signals and associated data is described. While more data is needed to validate the methodology developed, this study suggests that it can be possible to locate defects in the rail head within the desired precision if a known reference feature such as a bolt hole is nearby.

BACKGROUND

Rail head repair welding is a process in which a replacement weld can be made by replacing a portion of the rail head only. The technique provides a cost-effective method to remove transverse defects (TDs) in the rail head without disturbing the rail neutral temperature (RNT) of the parent rail. Successful rail head repair welds require precise location of the rail head defect to assure that it is successfully and completely removed during the welding process. Required location accuracy of the defect is within ±1 inch from the actual defect location. Figure 1 shows a photo of the typical width of rail that is removed during the rail head repair process before a weld is made.

Figure 1. Typical cut of the rail head during the rail head repair welding process

INTRODUCTION

TTCI previously demonstrated a phased array rail inspection prototype for detecting and characterizing rail defects. Data streams generated by this prototype contain position encoder information and GPS location data along with the ultrasonic scan data. The TTCI PAUT prototype has four independent phased array probes that scan in prescribed directions simultaneously. Using the known geometries and positions of the probes, it is possible to precisely locate defects within the rail based on the timing of the signals received at each probe. This work aims to determine the accuracy and precision of locating defects in the rail head from the PAUT data stream.

DATA FORMAT

Phased array data is saved as hexadecimal values in a database. Each array of the database is composed of 250 bytes of data. The order of the bytes represents the sequencing of the reflections received. The value of each byte in the array represents the magnitude of the reflection. The data array represents magnitude and timing of ultrasonic beam reflections from features inside the rail. Each reflection determines the sound path distance along a direction defined by the beam angle. The beam angle is defined for each scan, and there are multiple scans for each phased array probe.

DATA PROCESSING

To determine defect position, the data must be decoded. This involves converting each A-Scan from hexadecimal values to integer values, and then converting the integer values to the "true depth."

True Depth Conversion

Each integer value resulting from converting each A-Scan (also known as sample) represents the amplitude of reflection normalized from 0 to 255. By converting each sample to true depth, researchers identify the depth at which each amplitude value was recorded within the rail head. This is a function of beam direction. More specifically, defects can be characterized and identified by knowing the depth into the rail head at the specific angle. Figure 2 shows the amplitude values associated to a sample value.

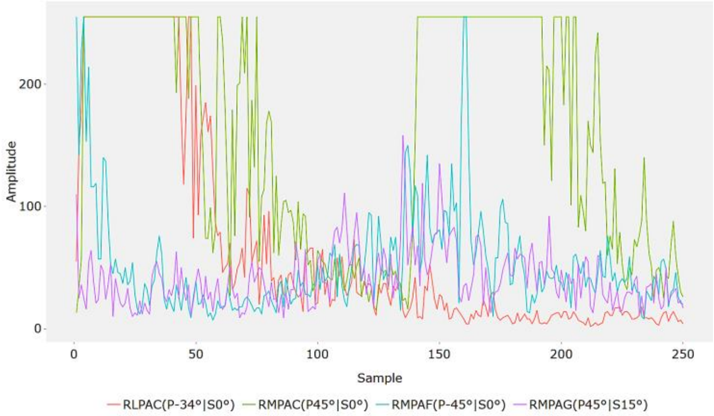

Figure 2. Representation of samples versus amplitude for different probes

The conversion process from samples to true depth starts by converting each sample value to the sound path. The sound path is a function of the point count, which is the total number of sample values. For this data set, the number of sample values for each A-Scan is equal to 250, the sample vector is represented by sample $= [1, 2, 3, \dots, 250]$, and range is presented in the database setup files and is expressed in microseconds (μs). The second step consists in converting the sound path into a length (inches). The length is a function of the sound path (μs) and the speed of sound $\left(\frac{mm}{\mu s}\right)$.

The third step consists on correcting the depth for the angle for each probe.

RAIL DEFECT DETECTION

This section describes the methodology developed to extract rail defect features using off-board phased array inspection data. Phased array data contains GPS and encoder entries related to vehicle position. GPS defines the location on a map to the nearest few feet. The encoder tracks distance along the rail and is accurate to within about a quarter milimeter. The encoder instrument, which contacts the rail, provides the trigger signal that begins each phased array scan. For this data set, the trigger is every 6 mm, or 22 encoder counts. The GPS and encoder data are stored in separate arrays that are synchronized with the A-scans during processing.

To identify rail head defects, the A-scan database was subset into groups based on the probe, primary angle, secondary angle, and cycle. For each combination of these elements, information about encoder and its corresponding true depth were plotted in a heat map (Figures 4 and 5). The heat map has 256 colors representing the reflection amplitudes.

The color code in the heat map shows the amplitude signal values for each encoder at a specific true depth. The lowest amplitude value is shown in dark blue and represents that there is no indication; whereas, yellow is equivalent to the largest amplitude value (255). Stronger indications (lighter colors) are used to identify known features or defects within the rail.

GPS coordinates within the data provide encoder value intervals that join common scan data tables. Since the GPS has an accuracy of 1 foot, the encoder values associated with each coordinate can be used as a starting point to find other encoder counts that are likely to be within the same GPS coordinate. Inspection cycles are triggered by the encoder based on a fixed number of counts. The fixed distances between the probes, the number of encoder counts, and the inspection angle dictated by the focal law can be used to determine the location of each defect in the linear direction. Figure 3 shows the probe configuration. Colored lines are shown to assist with visualizing inspection angles.

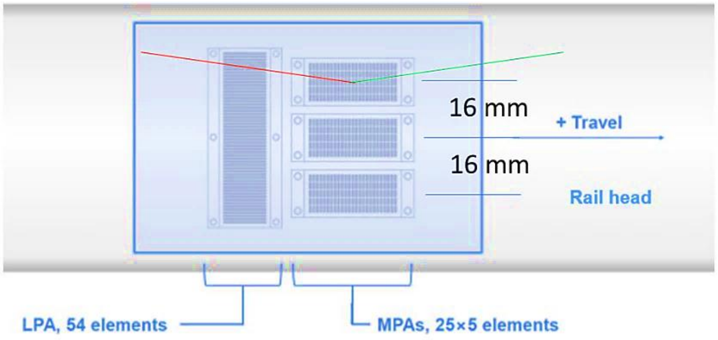

Figure 3. PAUT probe configuration: red line=15° secondary angle in the negative primary direction, green line = 15° secondary angle in the positive primary direction

Figure 4 shows indications in and near a weld from the linear phased array (LPA) in the zero degree direction (looking straight down into the rail head). As the probe traverses the weld joint (increasing encoder values from top to bottom,) several features are visible. The top of rail is at the transition to blue from the heavy yellow zone near zero depth. The bottom of rail is the blue-to-yellow transition at about a 7-inch depth. This is consistent with a 136-pound rail. There is a large reflection from a bolt hole in the web. The true depth of the top of this bolt hole is about 3.25 inches from the top of the rail. There also is an indication of a defect within the weld itself, about 2.25 inches below the surface. This indication is centered around encoder value 2,250. Notice a contour change at the weld where the top of rail indication distorts at the weld dip. This is due to the RSU membrane conforming to the weld dip and increasing the water path depth in that local region. Increased water path increases time of flight, which causes a localized distortion in the heat map.

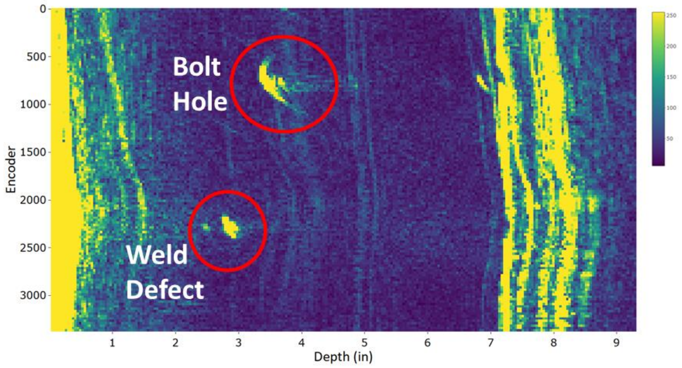

Figure 4. Heat map showing bolt hole and weld defect

Figure 5 shows the weld defect from a different probe and angle. It shows the view from the gage side matrix phased array (MPA) in the minus 45-degree primary direction, showing two defects.

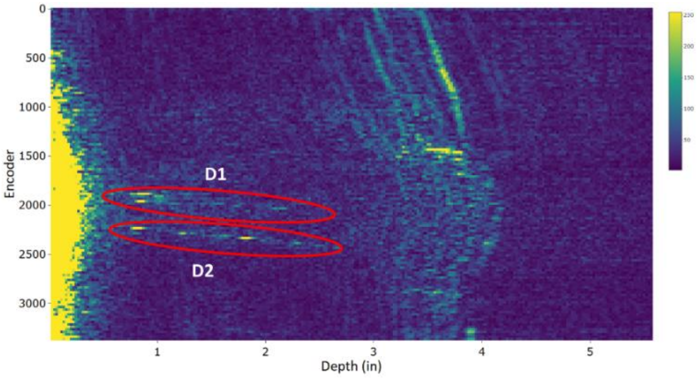

Figure 5. Heat map in -45° direction from the gage side MPA showing two transverse defects in the weld

Notice that there is no bottom of rail or bolt hole indication on this heat map. This is expected since this probe is not centered over the web, and the inspection angle is inclined 45 degrees from the surface away from the direction of travel. The head-to-web radius is visible as a lighter band in the 3- to 4-inch region, which is consistent with the 45-degree inspection angle. Finally, observe that the encoder values range from about 1,800 to 2,500, similar to the LPA indication. This is consistent with probe layout and inspection angle. The MPA passes over the defect before the LPA, but with a rearward facing inspection angle, additional encoder steps accumulate before the indication appears on the heat map.

LOCATING DEFECTS

To locate defects, researchers must work relative to a known datum in the rail. Features such as welds, bolt holes, and special trackwork are identifiable in the data and on the network. Using the GPS coordinate, the specific datum can be located by the repair crew. In this example, the bolt hole would be the reference datum. An inspector would then measure the given distance from the bolt hole to locate the defect.

ANALYSIS

In this example, encoder values increment by 22 counts every 6 mm. Therefore, starting with an arbitrary zero encoder count at the beginning of the scan, the bolt hole is centered about 8 inches (encoder count 750) from the start of the scan relative to the LPA. The TD is centered on encoder count 2,000 relative to the MPA, which places it at about 21.5 inches into the scan, relative to the MPA. The LPA trails the MPA by 1.25 inches in the direction of travel. This means the weld defect is located 12.25 inches from the bolt hole center according to the PAUT data.The largest source of error in this process is determining the extents of the indications.These values were derived visually from the heat maps, but could be encoded for extraction from the A-scan data based on amplitude.

Given this example, this technique provides the required accuracy to locate the transverse defect. But precision will depend on the measurement method used to find distance from the datum, especially as the distance increases. A tape measure would be suitable for distances up to 50 feet. For defects that occur on long stretches of parent rail where no reference datum is close by, a rail-contacting encoder on a push cart may be needed to maintain the required precision.

CONCLUSION

This *Technology Digest* presents a method to decode offboard phased array data for the purpose of locating defects. The phased array data provides GPS and encoder location information. The GPS data provides a location on the rail with an accuracy of within 1 foot. The encoder data was shown to be relatable to defect indications with about 12 mm (1/2 inch). If an identifiable feature such as a bolt hole, weld, or other track work feature can be identified in the near vicinity, it is possible for a repair crew to measure from the identified datum to the actual defect location within the required accuracy.

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