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LOCATING AND SIZING RAIL HEAD DEFECTS FOR RAIL HEAD REPAIR WELDS USING PHASED ARRAY ULTRASONICS

SUMMARY

Transportation Technology Center, Inc. (TTCI), as part of a cooperative effort between the Federal Railroad Administration (FRA) and Association of American Railroads (AAR), studied a new method to accurately locate rail head defects using onboard phased array ultrasonic testing (PAUT) data for the effective placement of rail head repair welds (HRW). In order for the rail HRW process to be effective, a defect location accuracy of ±1 inch is required. The study revealed that it is possible to locate defects in the rail head within the desired precision if a recognizable feature such as a bolt hole, rail end, or weld are nearby; that is, the method presented provides an accurate distance from a known datum to within approximately ±0.5 inch. The final precision of locating the defect depends on the distance of the defect from the datum as well as the measurement technique used to make the measurement. In the present work, the process of extracting and processing PAUT off-board data, as well as identifying rail head defect features using A-scan signals and associated data, are described.

BACKGROUND

Under a cooperative program between the FRA and the AAR (by way of their Strategic Research Initiatives program), TTCI completed a study to determine the ability to locate and size internal defects in a rail head using an in-motion, hi-rail-mounted PAUT nondestructive evaluation approach. TTCI previously developed a phased array rail inspection prototype for detecting internal rail defects in track [1].

A rail HRW is made by cutting out a portion of the rail head containing a defect and replacing it with a clean section of head material that is welded in using a thermite or flash-butt process. The technique provides a cost-effective method for removing transverse defects (TD) in rail without disturbing the rail neutral temperature. Successful rail head repair requires precisely locating the TD to assure it is completely removed during the repair process. Required location accuracy of the defect is ±1 inch from the actual defect location. Figure 1 shows a photo of a mold fitted to the rail and positioned above the cutout.

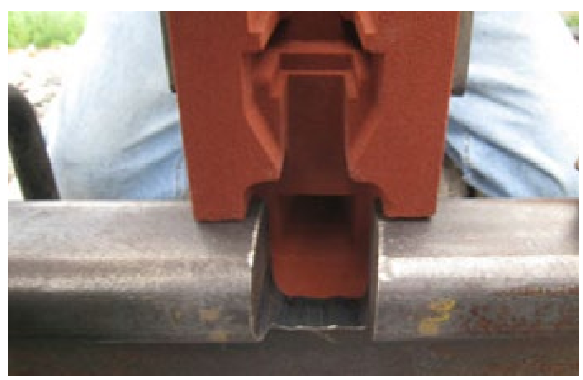

Figure 1. Thermite rail HRW process showing a portion of head removed with the mold fitted to the rail and positioned above the cutout

DATA FORMATS

Data from the TTCI PAUT 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. Figure 2 shows the probe arrangement on the TTCI prototype with three 125-element matrix phased arrays (MPA) and one transverse 54-element linear phased array (LPA).

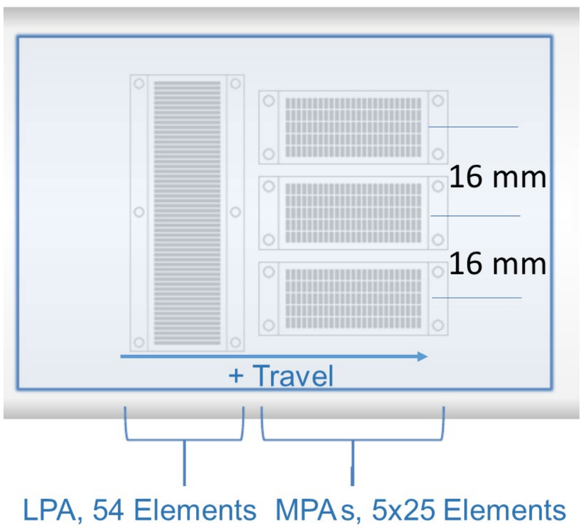

Figure 2. PAUT probe configuration

DATA PROCESSING METHODS

Data is stored in hexadecimal arrays of 250 bytes each. 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. Thus, the data array represents the magnitude and timing of ultrasonic beam reflections from features inside the rail. Each reflection determines the sound path distance along a particular direction defined by the beam angle. The beam angle is defined for each scan, and there are multiple scans for each phased array probe.

To determine defect position, the data must be decoded. This involves converting each A-scan to integer values and then converting the integer values to the "true depth." Each integer value represents the amplitude of ultrasonic reflection, normalized from 0 to 255. By converting each sample to true depth, the depth at which each amplitude value was recorded within the rail head is identified. This is a function of beam direction. More specifically, rail head defects can be characterized and identified by knowing the depth into the rail head at the specific angle. The conversion process from samples to true depth starts by converting each sample value to the sound path, as shown in Equation 1.

$$\text{Sound Path}_i(\mu s) = \frac{\text{sample}_i}{\text{digitizing frequency}} \quad (1)$$

where:

$$\text{digitizing frequency} = \frac{\text{Point count}}{\text{Range}}$$

Point count is the total number of sample values. The number of sample values for each A-scan is equal to 250 and the sample vector is represented by: sample = [1, 2, 3, …, 250]. Range is defined in the database setup files in terms of microseconds (µs).

The third step is converting the sound path (µs) into a length (inches), as shown in Equation 2.

$$\text{length}_i(in) = \text{soundpath}_i(\mu s) * \text{speed of sound}\left(\frac{mm}{\mu s}\right) * \frac{1\ in}{25.4\ mm} \quad (2)$$

where sound path value is associated to sample_i. The speed of sound (mm/µs) value is obtained from the setup files and is related to material (i.e., rail steel) velocity.

The fourth step is to correct the depth for the angle for each probe as shown in Equation 3

$$\text{true depth(in)}_i = \text{length}_i * \frac{1}{cos(radians(\text{beam angle}))} \quad (3)$$

where length_i is the length calculated from step 3 and beam angle is the primary angle associated to a beam. This process locates the defect indication in the scan data.

The next step is locating the defect along the rail. Phased array data contains GPS and encoder entries related to vehicle location. GPS defines the location on a map to the nearest few feet. The encoder tracks distance along the rail.

The encoder instrument, which contacts the rail, provides the trigger signal that begins each phased array scan. The trigger is every 22 encoder counts, or 6 mm. The GPS and encoder data are stored in separate arrays that are synchronized with the A-scans.

The A-scan database is subset into groups based on the probe, primary angle, secondary angle, and cycle. For each combination of these elements, information about the encoder and its corresponding true depth are found. A heat map is used to visualize the defects. The heat map has 256 colors representing the reflection amplitudes. Figure 3 is a heat map showing a bolt hole and a weld defect.

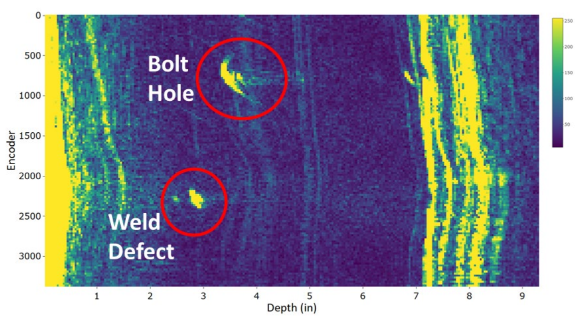

Figure 3. Heat map showing bolt hole and weld defect from the LPA

The color code in the heat map shows the amplitude signal value for each encoder at a specific true depth. The lowest amplitude value is shown in dark blue and represents no indication. Yellow is equivalent to the highest amplitude value (255). Stronger indications (lighter colors) are used to identify features and flaws within the rail. This scan is from the LPA in the 0-degree direction (looking straight down into the rail head). Several features are visible as the probe traverses the weld joint (increasing encoder values from top to bottom). 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-lb. 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 on encoder value 2,250.

Figure 4 shows the weld defect from the gage side MPA in the minus 45-degree primary direction. Two defects are visible within the weld.

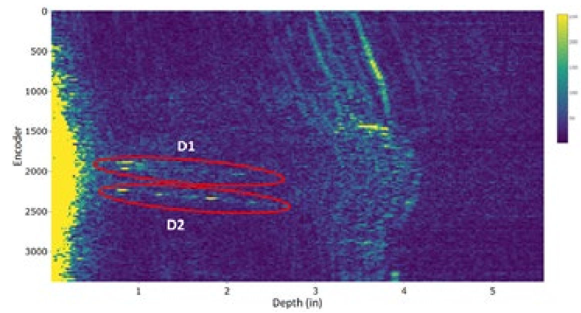

Figure 4. The -45 degree heat map from the gage side MPA showing two transverse defects in the weld

The indication 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, due to a rear-facing inspection angle, additional encoder steps accumulate before the indication appears on the heat map.

Figure 5 shows the +45-degree inspection angle from the same MPA probe. Here, the encoder values range from 1,500 to 2,100 for the pair of indications. Considering the probe configuration and forward inspection angle, this is consistent with expectations. Triangulating visually, the two transverse defects are located directly under the gage MPA when the encoder value is 2,000.

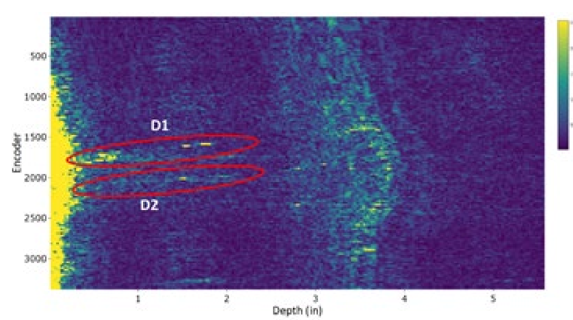

Figure 5. The +45-degree heat map from the gage side MPA showing two transverse defects in the weld

The LPA and gage MPA are 16 mm (0.63 in.) apart. The predicted defect position from the two readings differ by about 11 mm (0.43 in.); thus, the uncertainty is the difference or 5 mm (0.20 in.) between these indications. The greatest uncertainty comes from determining the extents of the indications, which is one encoder trigger increment, 6 mm (±0.25 in.). Locating the defect within the rail requires measurements relative to a known datum (e.g., the bolt hole). From the LPA PAUT data, the weld defect is located 311 mm (12.25 in.) from the bolt hole center.

CONCLUSIONS

A method to accurately locate rail head defects using in-motion PAUT data for rail HRW is demonstrated. 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 within 12 mm (0.50 in.). If an identifiable feature such as a bolt hole, weld, or other trackwork feature can be identified in the near vicinity, it should be possible for a repair crew to measure from the identified datum to the actual defect location within the required accuracy ±1 in.).

REFERENCES

1. Witte, M., et al. (2017, September). Rail Defect Detection Using Phased Array Ultrasound, Development of the TTCI Prototype. Report R-1021. Transportation Technology Center, Inc. Pueblo, CO.

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