Ultrasonic Inspection System for High-speed Rail Inspection

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Abstract

With the increase in transport volume, improving rail inspection efficiency becomes more important. Rail inspection is mainly using ultrasonic technology to cover both bulk and subsurface defects. Due to the limitation of data processing and conventional UT technology, it is very hard to deal with the relationship between inspection speed and ultrasound coverage. Now mainstream inspection car can reach maximum speed of less than 80Km/h. In order to achieve higher inspection speed, we are trying to build an inspection system combining phased array (PA) technology and high-speed processing algorithm. Also, fast phased array has been used for improving Probability of Detection (POD) of typical Transverse Defects (TD) in rail head. Meanwhile high-speed processing algorithm gives us potential to process data in parallel and discriminate defect type automatically, such like bolt-hole cracks, transverse defects etc., by setting certain channels’ combination conditions. During the experiment, inspection speed of 108Km/h is simulated. The results shows the system can handle the data flow in such speed.

Keywords: rail inspection, high-speed, phased array, high-speed processing algorithm

1 Background

As one of the most important safety factors, the rail is exposed to wide range of stresses, which are coming from contact loads, temperature variation, corrosion or residual internal stresses from manufacturing process. Due to the difference of operation condition, the defects in rail are virious. The mainly defect occurred in Chinese heavy haul lines is transverse defect, as shown in Figure 1, which is caused by extending of details fracture, squats, shells and head wear and they are often found at the side of rail head contacting with wheel tread [1-2].

![Figure 1: Transverse Defects](image-url)
TD is not easy to be detected. Rail inspection equipment mainly base on conventional ultrasonic technology, and 70° angle beam is mainly applied. And there are two ways for TD inspection, one by direct scan technique, the other is using double traverse wave to interact with defects, as shown below.

![Figure 2: Schematic of 70° beam inspection with double traverse wave](image)

It is very important to use right deflection of the probe to make ultrasound have good interaction with defects. PA of course can be used for improving POD, but the inspection speed is limited due to data processing ability.

This paper shall discuss the probe arrangement for typical defects inspection and it is very sensitive to TD even in high speed inspection, furthermore the matched data processing system has been built for processing data fast with automation.

2 Solution of Transverse Defect inspection with Fast phased array Technology

Fast phased array technology uses one phased array probe to transmit multiple acoustic beams with only one shot, then receive and process all channels defect echo wave simultaneously. Basing on this technique, they developed a UT phased array system, which is especially designed to meet with the high productivity inspection demands, thanks to its outstanding capability at replacing multiple conventional Phased Array systems working in parallel. And the FAAST uses a classic phased array approach to find defects [3]. And according to the study, double traverse wave can interact with transverse defect in a better way with weaker scattering [4]. We may combine the advantage of FAAST and double traverse wave method to improve inspection speed and POD at the same time. As shown in Figure 3, using FAAST, offset PA probe with multi-beam can cover head gauge area effectively, the coverage rate reach more than 50%, much than one beam-coverage rate by conventional offset 70° probe.
Also, it is very necessary to discuss the offset angle of PA. If the incident angle is not large enough with small offset, the beam cannot cover the target. Thus with relative small offset, the incident angel should be large. But with the increasing of angle, it is getting harder to get high SNR, according to the simulation. It is appropriate to set the off-set between 16°-20° with the multi-angle beam from 60°-70°.

**3 Probe arrangement**

In order to control costs and take advantages of some typical angle, the arrangement combing UT and PA probes. And these probe will be put in the probe carriers as shown in Figure 5.
This probe arrangement can be very sensitive to the TD without sacrificing inspection speed. Besides PA, 0° UT is put in the middle of central axis of the rail head, which can be used for covering the middle of rail, from the subsurface (about 5mm under the surface) to the rail base. The beam width roughly cover the whole width of rail web. And 37° UT is very sensitive to the bolt-hole cracks, oblique cracks, transverse defects in rail base.

4 Rail inspection system

4.1 System composition

Basing on the probe arrangement, the inspection system can be made up by ultrasound data processing host unit based on FAAST, defects automatic judgment, classification system, interactive software and accessory calibration system.

4.2 High-speed data processing flow

High-speed data processing flow for rail defect is shown as Figure 6:
4.3 Critical algorithm

High-speed data processing flow uses many complicated and precised algorithm module, mainly includes:

- Data collecting algorithm module.

It can collect ultrasonic data at high-speed with configurable PRF (pulse repeated frequency) and then convert analog ultrasonic data to digital data with 16bits precision.

- Single-Channel defect judging algorithm module.

Its function is to filter noise data and reserve defect data by setting filter threshold value and number of continuity point which is across the threshold value.

- Location correction algorithm module.

Firstly convert defect digital data to horizontal length and vertical length, then calculate the defect’s horizontal location and depth location by mileage calculation algorithm and depth calculation algorithm.

- Expert diagnosis algorithm module.

It is an important module to monitor the multiple relevant channels and recognize real defect by judging the defect mileage location, defect depth location, defect size from all relevant channels simultaneously.

- Defect information extracting module.

This module can extract the information about the defect recognized by expert diagnosis algorithm, include defect type, defect mileage location, defect depth location, defect size, etc.

4.4 Simulated Verification by Reference Rail
To verify the system performance, use reference rail, see Figure 7, as platform to collect real defect data, and then put defect data into excel file and download to simulation system, system sends defect ultrasonic simulated data to high-speed rail inspection system at simulated speed of 108km/h.

As figure 5 shows, high-speed rail inspection system can correctly recognize joint, bolt hole and bolt hole crack, automatically mark bolt hole and suspected bolt hole crack, and display the defect and relevant defect information.

By complete testing, high-speed rail testing system can effectively recognize fifteen defects including defect of transverse flaw, bolt hole crack, crack in rail web and rail base, horizontal crack, weld defect, etc. and provide specific defect information.

**Figure 7: Defect distribution of reference rail**

**Figure 8: Testing result of Joint, Bolt Hole and Bolt Hole Crack**

### 5 Conclusion and outlook

Rail inspection system in this paper is capable of detecting typical defects in reference rail. Comparing to the conventional arrangement, the coverage ratio of rail head has been improved. Especially the utilization of FAAST-PA gives the arrangement more potential to detect the transverse
defects in rail head. By simulation, corresponding high-speed data processing flow and critical algorithm has been verified. And this system has been testing in Australia, practical conditional is much more complicated than theoretical analysis, we shall strive to make it better.

References


