An Ultrasonic technology Study for Subsurface Defect in Railway Wheel Tread

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Abstract

The subsurface defect in the wheel tread caused from Rolling Stock Fatigue (RCF) has become more danger in high speed railway. The conventional UT and phased array UT have deficiency to find the subsurface defect from the tread surface because of limitation of ultrasonic near field. In this paper, the subsurface defect is studied by simulation and experimental results with ultrasonic technique. Two typical probes, TR and angle probe are employed and some parameters are optimized. The experiments on real wheel with nature subsurface defect are carried out and the results show that it can compensate for conventional ultrasonic technology to improve the Possibility of detection (POD) in the railway wheel.

Keywords: Ultrasonic Testing (UT), railway, subsurface defect, Railway wheel

1. Introduction

The wheel is one of key components on train, and the failure of wheel may cause serious accident, especially in high speed and heavy haul railway. In general, ultrasonic inspection technology is used successfully for defect detection in the life time of wheel. The increasing requirement for the reliability, availability to make sure maximized safety on rolling stock are the most emergence targets of China railway system, especially for the CRH high speed trains. So those ever increasing demand is strongly influencing the development and application of NDE system. Based on the research results of phased array ultrasonic testing technology about wheel and axle of EMU, one comprehensive testing system about CRH type EMU wheel-set are set up and some automated phased array ultrasonic testing equipment corresponding to each level of the flaw detection system are developed. There has been build one wheel safety ensure system in china high speed railway (CRH) [1, 2].

The subsurface crack is feature of narrow reflect area, small size and at near field of ultrasonic technique, so conventional UT systems are always with low possibility of detection (POD). Meanwhile, the literate studies show that pulse eddy current (PEC) probes perform far better to detect the rail defect but with lift-off variation problem [3]. Alternating current field measurement (ACFM) have a good potential for quantification RCF with maximum operating lift-off at high speed, but ACFM is not sensitive for subsurface [4]. Electromagnetic acoustic transducer (EMAT) can generate the surface wave to detect RCF at a small lift-off [5].

However, for existing wheel detection systems, all those inductive methods need external equipment. The aim of present work is to provide an optimization solution to detect the subsurface defect in rail wheel tread based on the existing wheel detection system. The model of subsurface defect is studied and detection method by UT is analysed in simulation. Some key notes are discussed based on the subsurface defect features and then the solution for enhanced UT result is studied in simulation and experimental results. Meanwhile, the results from multiple UT channels are compared and evaluated according to the relationship between defect feature and probe classes. All those results and conclusions show the validation of those optimization solutions for subsurface defect.

2. Methodology

2.1 Modelling and detection
The railway wheel-set is with high fatigue stress under the wheel tread 5~45mm [6] caused by the wheel-rail rolling contact fatigue. Those fatigue cracks are sources for some critical damage in wheel tread, even cause the deadly danger for train’s safety. Subsurface crack is one of typical fatigue in wheel tread, especially under condition of high speed train with high cycle loads. In generally, those subsurface cracks are with small size about 2~4mm depth, less 1mm width and about 10mm length. One of typical crack is found in field as shown Fig. 1, it’s blind in the surface as Fig. 1 (a), but after 2mm depth material machined, the crack was observed clearly as vertical one with 15~20mm curve length, shown in Fig. 1 (b).

![Fig. 1 subsurface crack image: (a) the original image at tread surface, (b) after machined 2mm result.](image)

Several typical cracks are modelling at wheel tread. Model (a) and (b) are Vertical crack and transverse crack separately; model (c) and (d) are angular crack, as shown in Fig. 2. The feature of all those cracks is at subsurface and with small size. Some of those cracks disappear automatically during the wheel in service, but some propagates into the surface and becomes the danger one for train safety [6]. So it is necessary to detect it and monitor its status frequently.

![Fig. 2 Subsurface crack in wheel tread](image)

Most wheel ultrasonic system use Longitudinal wave (L-wave generated by TR probe) to test circumferential defects in the wheel rim and angle transverse wave (T-wave generated by angle probe) to test the angular defect in the tread. But it is difficult to be detected and evaluated for those subsurface cracks by ultrasonic technique from wheel tread by manual. In this paper, some optimization works are employed to existing UT system to enhance the POD for subsurface crack.

### 2.2 Simulation

The crack models are built and detected by UT in CIVA software, and then some optimization are analysed. Two conventional UT probe are used, one is double elements longitudinal probe
(named TR), and another is phased array angle probe (named angle probe), as shown in figure 3. According to the model in Fig. 2, angle probe is suitable for model (c) and (d). TR probe is good for model (b) with bigger reflector area. The model (a), vertical crack is difficult for both probes, angle probe is possibility one to detect it.

![Fig. 3 Detection for subsurface crack in wheel tread: (a) angle probe for angular crack, (b) TR probe for angular crack, (c) TR probe for transverse crack](image)

There are two typical subsurface cracks: one is vertical crack with 3mm depth, 0.5mm width; another crack is “Λ” shape surface crack with 3mm depth and 20°. Probe scans over crack area with 0.5 mm resolution, so the A scan data and B scan image can be acquisition in simulation. Under simulation condition, both surface rough and ultrasonic coupling all are in good condition, so detection for subsurface crack as 1mm depth still provides good results, the same results happen for angular cracks in model (c) and (d) by angle probe.

As previous discussion, the vertical crack with no echo face can’t be found by TR probe, but angle probe can be used to get echo wave, as shown in Fig. 4. Three incident angles are studied with 45, 60 and 70 degree, centre frequency as 2MHz, the bigger angle the stronger echo wave.

![Fig. 4 Angle probe for vertical crack](image)

### 3. Experiment

A basic experiment and test work based on ultrasonic technique is carried out in a wheel testing experiment system. As shown in Fig. 5, the wheel testing experiment system is based on compound usage of phased array ultrasonic and conventional ultrasonic inspection technology, and robotic technology, defects in wheel flange, wheel rim and wheel disk are automatically and efficiently inspected with wheel set mounted on a train[7].
A TR probe array is designed to cover the tread area, especially the important rolling contact area. Those probes are placed side by side with a bit overlap to avoid ultrasonic beam cover blind. Meanwhile, two pairs of angle probe are used to detect rolling contact area in tread as shown in Fig. 6. In general, TR and angle probes are used to detect the wheel tread and web area with long distance ultrasonic path and with low resolution for small data size, so it is with low resolution for near surface area. A special configuration for TR and angle probe is set up only to detect a subsurface crack in wheel tread, some typical parameters are used in this configuration as depth for 0~10mm, low alarm threshold value at 20%, high sample frequency up to 100MHz, etc.

### 4. Result and analysis

There are two wheels with different crack in this experiment. One wheel is with artificial defects machined in wheel tread, where one is surface crack with 2mm depth and 1mm width. Another wheel is with a natural crack in wheel tread, which is about 5mm length, 0.5mm width and 4mm depth by analysis result, as shown in Fig. 7.

![Fig. 5 Experiment setup](image)

![Fig. 6 the probes configuration at wheel tread](image)

(a) ![Fig. 7 the crack on wheel tread: (a) artificial crack](image)  
(b) ![Fig. 7 the crack on wheel tread: (b) natural crack](image)
Two types of probe, TR and angle probe are installed at the same probe holder to test those cracks at the same time. In Fig. 8, the index 1 is echo image for artificial crack as shown in Fig. 7(a). It can be observed that echo wave is wick by TR probe because of narrow reflection area for this crack. However, the echo wave is stronger by angle probe than TR probe with the same detection sensitivity, which is similar result comparison to simulation results in Fig. 4.

![Fig. 8 artificial crack detection result: (a) angle 30° probe result, (b) TR probe result](image)

For the natural vertical crack, testing results are shown in Fig. 9. Echo image in Fig. 9(a) is good SNR and can be seen clearly. Otherwise, amplitude of echo wave by TR probe decreases and it is with strong coupling noise near subsurface area.

![Fig. 9, Natural crack detection result: (a) angle 30° probe result, (b) TR probe result](image)

Although the TR probe provides bad results for those small subsurface vertical cracks comparison with angle probe, it is also good cross-reference result for analysis and verifies the decision. During the testing, the scanning resolution for those probes was set to at least 0.5 mm to get at least 5 acquisition points dependent on the probe size.

In general, the echo signal with some coupling noise at near surface even disappears in the noise. Some image processing can be employed to remove the coupling noise based on the image features for wheel tread testing.

5. Conclusion

In this paper, the subsurface cracks detection by TR and angle probe is studied. Through the simulation and experimental result, the conclusions can be got as following:

- The subsurface vertical crack and transverse crack at wheel tread can be detected by angle probe and TR probe separately with some optimization parameter, such as the high scanning resolution and high acquisition data in ultrasonic near field.
- The echo wave detection by angle and TR probes for the same detection area provides a cross-reference and verification for defect evaluation.
The good coupling condition is one of key point for ultrasonic technique, especial detection of subsurface defect in field. In the future, some ultrasonic image processing will be employed to enhance the SNR of echo wave image.

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**References**


