High-Power Locomotive Solid Axle Defect on-line Detection Technique

Chaoyong PENG, Li WANG, Xiaorong GAO, Zeyong WANG, Quanke ZHAO, Yu ZHANG, Jianping PENG, Kai YANG

Non-destructive Testing Research Center, Physics Science & Technology School, Southwest Jiaotong University
Chengdu, China; Phone: +86 61337828, Fax +86 61337838; Pengmd@163.com, wangli.net@263.net, gxrr@263.net, wzy590107@163.com, zhaquanke@126.com, zhang.yuer@163.com, peng.jian.ping@126.com, yangkai_swjtu@163.com

Abstracts

The quality of solid axle is especially important for the safety of the high-power locomotive. A technique and system for on-line Chinese high-power locomotive solid axle defect detection based on phased array ultrasonic technology is described in the paper. Advanced phased array ultrasonic technology, ultrasonic transmitting and receiving principle, method for solid axle defect detection is explained in detail. With this method, most transverse defects located along the axle can be detected by opening and inspecting from the end side of solid axle. The on-line solid axle inspection system with phased array probe and device, automatic electromagnetic fixing and scanning mechanism, electronic control device, computer and software is shown. The results of ultrasonic detection are displayed in A scan, B scan and C scan for operator analyzing. With the described technique and equipment, one solid axle can be automatically inspected within five minutes and results are well recorded and reported.

Keywords: solid axle, defect detection, phased array ultrasonic, high-power locomotive

1. Introduction

As one of the most important transportation, the safety of railway is paid much attention to. No big defect is allowed on railway wheels and axles, especially for high-speed train and high-power locomotive. Some countries have had high-speed train wheel and axle safety monitoring and inspecting method and systems, such as Germany and China. German railway system (DB AG) has built up an automatic safety guarantee system for wheel with stationary wheel ultrasonic testing system AURA [1][2][3] and mobile wheel ultrasonic testing system UFPE [1][4], and stationary and mobile axle ultrasonic testing system SHUTTLE. Chinese Railway High-speed (CRH) also has its method and equipment for stationary and mobile wheel and axle ultrasonic testing [5].

In China, more than 15000 normal locomotive and 5000 high-power locomotive is put into application. The wheel and axle defects are detected regularly with ultrasonic and magnetic particle testing. However, the ultrasonic testing of locomotive axle is mostly down manually. With a portable ultrasonic instrument, the axles are inspected from end side of the axle by changing from one angle probe and another angle probe to cover different parts. All the work is down by hand and it is time consuming, and the defect is hard to distinguish from the back echo, and the data is difficult to manage.

An on-line mobile railway solid axle defect detecting method and system by using phased array ultrasonic technique is described in this paper. The system configuration, working principle, system controlling signal and work flow, data processing, results displaying is shown in detail.
2. Ultrasonic detection method

2.1 Phased array technique [5][6]

The principle of phased array ultrasonic is shown in the right part of Figure 1. The composite crystal for generating ultrasonic wave is cut to small pieces which are called ‘Element’. Typical phased array elements are shown in Figure 2. Each element is connected to ultrasonic electronic channel. Phased array system pulses and receives from multiple elements of a phased array probe. These elements are pulsed in such a way as to cause multiple beam components to combine with each other and form a single wave front traveling in the desired direction. Similarly, the receiver function combines the input from multiple elements into a single presentation. The general ultrasonic wave generated by a phased array probe is the superposition of the ultrasonic wave from each element.

![Figure 1: Phased array principle](image1)

![Figure 2: Typical phased array elements](image2)

The ultrasonic beam from a phased array probe can be changed by generating each element at different time sequence which is called ‘Focal law’. Because phasing technology permits electronic beam steering and focusing, it is possible to generate a vast number of different ultrasonic beam profiles from a single probe assembly, and this beam steering and focusing can be dynamically programmed to create electronic beam steering and beam focusing, as shown in Figure 3.

![Figure 3: Beam steering and focusing](image3)

2.2 Solid axle inspection method

For on-line application, the wheel-set is undisassemble and the end of solid axle is the only part for ultrasonic coupling, so the end cover of solid axle should be opened before inspection. Phased array probe is put on end of the solid axle. Different working models are used for full ultrasonic beam cover, as shown in Figure 4.

![Figure 4: Ultrasonic inspection models](image4)

With ±30° beam steering of phased array ultrasonic, most part of the solid axle can be covered, as shown in Figure 4(a). Most parts can be inspected twice by positive angle beam and negative angle beam, and the influence of the bolt hole can also be reduced. In this model, the corner area of the axle shoulder and wheel seat is blind area. The second sound path is used to cover this area, as shown in Figure 4(b). In this model, the blind area can be reduced.
to about 5mm from the corner. In the third model, the phased array probe is working in longitudinal wave, and the general status of the axle material can be evaluated, as shown in Figure 4(c). By rotating the phased array probe while the phased array probe is work in these three models, half of the solid axle can be fully covered and inspected.

2.3 Ultrasonic detection ability

With this method, transverse crack located at different position can be detected and the crack detection ability is decrease according to the distance from end of axle.

1. Detection ability at axle neck: 0.5mm depth transverse crack.
2. Detection ability at wheel seat: 2mm depth transverse crack.
3. Detection ability at gear seat: 2.5mm depth transverse crack.
4. Detection ability at middle part: 3mm depth transverse crack.

3. System Configuration

3.1 Mobile trolley and ultrasonic scanner

The whole system has two parts, mobile trolley and ultrasonic scanner. Mobile trolley is easy for on-line inspection application. Industry computer, input and output devices, phased array electronic device, ultrasonic scanner, ultrasonic scanner controller, coupling system, UPS and power supply cable is installed in the trolley, as shown in Figure 5.

The ultrasonic scanner is a key part for on-line solid axle inspection. The scanner is attached to the end of the axle with a positioning bar, and can be fixed on end of axle by powering on the electromagnetic, as shown in Figure 6. The phased array probe can be rotated clockwise
and counterclockwise by scanner with stepper motor. All these parts are compressed into a small space to decrease the weight and protect the scanner from dropping.

3.3 System control

The system signal chart is shown in Figure 7. The system is controlled by an industry computer. Phased array electronic device is linked to the computer by Ethernet. The ultrasonic inspection parameter is downloaded to phased array electronic device, and the ultrasonic beam is generated and received by phased array probe according to scanner encoder signal. The ultrasonic scanner is used to rotate the phased array probe for 360 degree to cover the whole axle. A stepper motor and compact rotation mechanism is driven by scanner controller. Encoder is used for positioning and triggering phased array ultrasonic. All the ultrasonic data analyzing and inspection report is done by computer.

The system flow chart is shown in Figure 8. After fixing the ultrasonic scanner on end of axle, axle information is needed for reporting. According to type of the axle, the existing inspection parameter is downloaded to phased array electronic device. By pushing the start button, then the system is working automatically. The ultrasonic scanner is rotating while the phased array ultrasonic beam is working in different model to detect defect in the axle. After 360 degree data acquisition is finished, data analyzing is started. Ultrasonic signal is displayed in A scan, B scan and C scan, and then the axle status is evaluated and reported. The inspection time for half axle is less than 2 minutes and two sides inspection is in 5 minutes.

4. Inspection results

The system control and data analyzing is done by professional software. Real time A scan
and ultrasonic coupling status is displayed when having axle data acquisition. After data acquisition, the data analyzing software starts working automatically. The sound path of each beam is calculated. The position of the finding is calibrated according to the sound path and angle information from ultrasonic scanner encoder.

The ultrasonic inspection results are displayed in three levels, A scan, B scan and C scan, as shown in Figure 9. In C scan, the key geometry of the axle is drawn to show the relative position of each finding and ultrasonic sound path is drawn to show how to catch the finding. In B scan, 360 degree data of each ultrasonic channel is shown separately. It’s easy to distinguish the real defect and the geometric echo from axle itself, such as echo from geometric corner and influence from bolt holes. By clicking the cursor in B scan, related A Scan is shown in the right of the screen.

After all the findings are confirmed by operator, inspection report can be exported in fixed format, including unfold axle view of C scan, list of defects, position and amplitude information of defects. A scan and B scan is optional to export as detail description of defects.

5. Conclusions

An on-line mobile automatic railway solid axle defect detection system by using phased array ultrasonic technique is described in this paper. Advanced phased array ultrasonic technique and method are applied on on-line solid axle defect detecting. The system configuration, inspection principle, system controlling and working flow, ultrasonic results displaying is shown in detail.

By using this technology, defects located at different position and in different size on solid axle can be found out successfully. Half of a solid axle can be fully inspected in 2 minutes only with opening the end cover of axle. The inspection time is saved and defect detection ability is increased.

Now, a number of on-line mobile railway solid axle inspection systems named “LZM” are used for Chinese high-power locomotive. It can also be used for normal locomotive and other solid axle transportation.
References

5. Chaoyong Peng, Xiaorong Gao, et al., 'Automatic Railway Wheelset Inspection System by Using Ultrasonic Technique', 7th ISPEMI 2011, August 7-11,2011, Lijiang, Yunnan, China