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Ultrasonic Phased Array Inspection for Gas Pressure Welds Joint of High Speed Railway

Abstract. *Ultrasonic phased arrays offer many advantages for industrial inspection due to increased flexibility over methods involving single-element probes. This paper will compare and contrast two previously-developed methods for the inspection of gas pressure rail welds involving phased arrays: the swept sector scan and the total focusing method, with particular emphasis on the latter. The total focusing method requires the acquisition of the full data set of time-domain signals from every possible send-receive combination in an ultrasonic array and the computation of time delay laws that will allow focusing at the post-processing stage. While applying conventional single probe ultrasound tests methods to detect the gas pressure rail welds, it is needed to use various beam angles for different detecting regions, resulting in long time and low efficiency of testing process. In comparison, ultrasonic phased array technique has the advantage of flexibly adjusting scan angle so as to improve testing efficiency. By using the CTS-602 type phased array instrument and trails on the gas pressure welding rail joint sample with artificial defects, the reasonable inspection parameters and testing programs could be determined, Experiments results show that the ultrasonic phased array inspection provides excellent test quality and good test efficiency. Based on combination of S-scan and B-scan plotted into 2-D isometric part, the defects features could be reconstructed and measured into a soft package. Comparison between A-scan plotted data and S-scan image data of defect sizes and position are also presented.*

Streszczenie. *Przedstawiono fazowa matrycę ultradźwiękową do przemysłowego badania nieniszczącego. Porównano różne systemy do badania połączeń spawanych w systemach kolejowych. System wymaga zebrania całego zestawu danych z matrycy ultradźwiękowej a następnie przetwarzania numerycznego danych. W proponowanym systemie nie jest konieczne badanie spawu pod wieloma kątami co zwykle jest czasochłonne. (**Ultradźwiękowa matryca fazowa do nieniszczącego badania jakości połączeń spawanych dla kolei dużych prędkości**)*

Keywords: Terms—rail; gas pressure welds; ultrasonic phased array; non-destructive testing
Słowa kluczowe: badania nieniszczące, badania ultradźwiękowe, jakośc spawu.

Introduction

Mobile gas pressure welding technique play an important role in continuous welded rail line (CWR) construction of high speed railway in China. Gas pressure welding is a solid-state welding technology which using oxygen-acetylene gas flame heating the work piece ends, then exerts enough pressure to form a solid-state welding joint. By the advantages of its convenient equipment, which easy mobile of online and offline, relatively simple operation, in addition to the superior strength, toughness and fatigue resistance of pressure welding joint, gas pressure welding of rails has become an important means of welding joints. Over the years, with the rapid development of continuous welded rail, gas pressure welding of rails as a seamless line of rail joint welding has been widely used on the high speed railway construction in China.

Some typical defects such as lack of fusion, shrinkage, porosity and coarse grains that may occur in gas pressure rail welds [1-4]. According to Nanchang Railroad Administration safety data for the five years recently, the defects of rail welds joint were the first leading cause of track failures in the China with about ¥900M in associated damage and repair costs [5]. The inspection work for detect gas pressure welding is considered to ensure the safety of railway; detection methods are now commonly using the ultrasonic technology [1]. While applying conventional single probe ultrasound tests methods to detect the rail joint of gas pressure welding, it is needed to use four or five probes with various inspection beam angles for different detecting regions, resulting in long time and low efficiency of testing process. What's more, the Chinese railway routine testing of rail welding joints nearly as many as 3 million, the workload of detection is too heavy.

In the field of nondestructive testing, in recent years a research hotspot is the ultrasonic phased array inspection technology [6-12]. Ultrasonic phased array is an inspection method that can utilize and display several A scans (stacked A scans) at any given time, various angles and predetermined focal lengths. Ultrasonic phased arrays are created by transducers containing multiple elements (arrays) which are excited by (phased) varying electronic time delays to create beams: linear and sectorial. Phased array offers significant technical advantages over conventional single-probe ultrasonic, the phased array beam can be steered, scanned in linear mode, swept in sectorial mode, and focused at a chosen depth of interest. Compared to the conventional single-probe ultrasonic inspection, ultrasonic phased array has the dominant features such as high speed, flexibility, various inspection angles, imaging inspection. Scanning with phased arrays is normally faster than single probe conventional mechanical systems, and phased array instrument has the ability to use multiple elements to steer, focus and scan beams with a single transducer assembly which has a wide variety of inspection angles can be used, depending on the requirements and the array. The new inspection technology showing a "true depth" image of defects is much easier to interpret than a waveform, the data can be saved and re-displayed as required. For example, detection and data plotting of porosity of welds using ultrasonic phased array as shown in figure1.

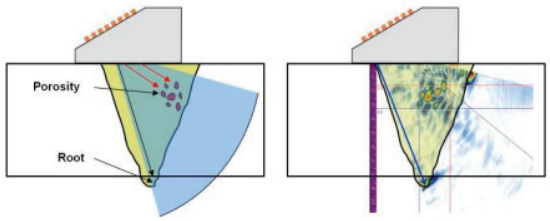


Fig. 1. Detection and data plotting of porosity of welds using ultrasonic phased array

As shown in Figure 1, beam steering permits the selected beam angles to be optimized ultrasonically by orienting them perpendicular to the predicted defects (e.g. lack of fusion, shrinkage, porosity, etc.) that may occur in gas pressure rail welds. In inspection using conventional ultrasonic transducers neither beam steering nor beam focusing are possible. Due to the micro structural nature of gas pressure welds (i.e. coarse grains) most of the energy injected in the weld is attenuated in the upper sections of

the rail and therefore defects that are present deeper can remain undetected. In the case of ultrasonic phased arrays, this problem can be addressed by steering and focusing the beam at the sections of the weld where defects may be present. Although signal attenuation is a problem for ultrasonic phased arrays too, the energy of the interrogating beam can be increased through focusing and therefore inspection of the deeper parts of the weld becomes possible. Electronic focusing therefore permits optimizing the beam shape and size at the expected discontinuity location.

Phased array ultrasonic technology as an effective visual ultrasonic testing, the main feature is the computer-controlled excitation and receiving of individual elements in a multiple element probe. A phased array probe consists of multiple piezoelectric elements, and small wave fronts from those elements can be dynamically time-delayed and synchronized to steer and focus an ultrasonic beam [13]. Two main characteristics of the phased array testing are flexible beam angle adjustment and dynamic focusing [14-16].It is possible that a properly designed phased array probe can perform several different inspections without changing hardware thereby reducing inspection time. So utilizing focuses and deflects of ultrasonic phased array to detect rail joint of gas pressure welding is expected to make high detection efficiency possible. In the paper, through detecting machining flaws of gas pressure welding by the technology of ultrasonic phased array, validate the effectiveness of the designed experiment, also, summarize the characteristics of ultrasonic phased array method for the rail joint of gas pressure welding.

System Description

Experimental System

The experimental system of ultrasonic phased array detects gas pressure welding as shown in Figure 2. In the paper using the phased array instrument CTS-602 produced by Shantou Institute of Ultrasonic Instruments Co., Ltd, CTS-602 is the first ultrasonic phased array flaw detector made in China, with independent intellectual property rights. Integrating computers, electronics, machinery, technology, manufacturing and other high-technology, with the characteristics of index advanced, function powerful, image clarity, and stable performance.

CTS-602 contains pulse ultrasonic test and ultrasonic phased array detection modes, using the USB interface can directly export the results to facilitate data storage. With 32 physical channels, supporting 16, 32, 64 or 128 probe array elements, bipolar square wave emission, and transmitted pulse width can be adjusted also. Scan modes include linear scanning and sectorial scanning, linear scanning beam adopts the same angle to scan electronically in one axis, and sectorial scanning beam adopts the angle in a range to scan electronically.

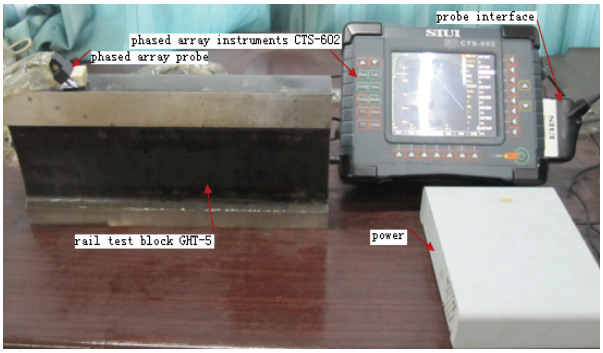
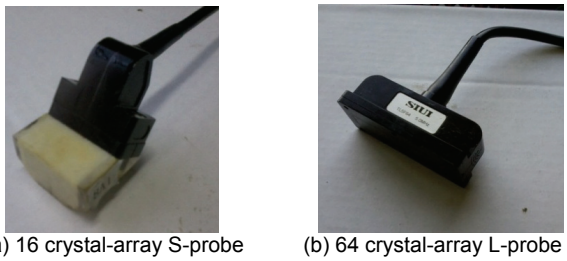


Fig. 2. Experimental system of ultrasonic phased array detects for rail joint of gas pressure welding

During phased array sectorial scanning, using 16 elements linear array probe, the probe as shown in Figure 3(a).The distance between two crystals is 0.5mm, probe frequency is 4.0MHz, 36° wedge angle. During phased array linear scanning, using 64 elements linear array probe, the probe as shown in Figure 3(b).The distance between two crystals is 1mm, probe frequency is 5.0MHz.



(a) 16 crystal-array S-probe (b) 64 crystal-array L-probe

Fig. 3. Phased array probe

Refer to ultrasonic testing of rail weld described in weld railway industry detection standards, using a special rail test block GHT-5 to certain sensitivity. Different regions of GHT-5 as shown in Figure 4, the diameter of all the cross-holes in region-A is 5mm, the diameter of all the cross-holes in region-B is 3mm, the diameter of all the vertical -holes in region-C is 4mm. The linear scan sensitivity determined by region-A, the sectorial scan sensitivity of rail head and rail web determined by region-B, the sectorial scan sensitivity of rail base determined by region-C.

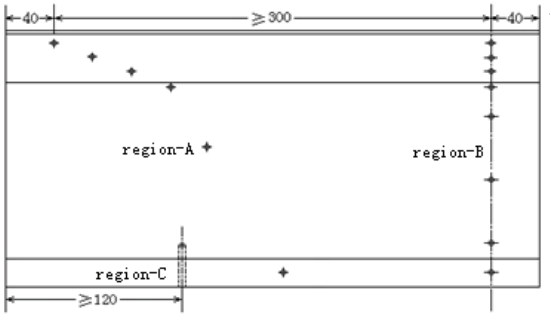


Fig. 4. Different region of GHT-5

Test specimen and defect size

In this study, test specimen of gas pressure welding containing machined defects, designed by the Public Works Jiujiang section of Nanchang Railroad Administration. The test specimen and defects location / size as shown in Figure 5. The hole diameter in rail head and rail base is 4mm, cross-hole diameter in rail waist is 5mm diameter.

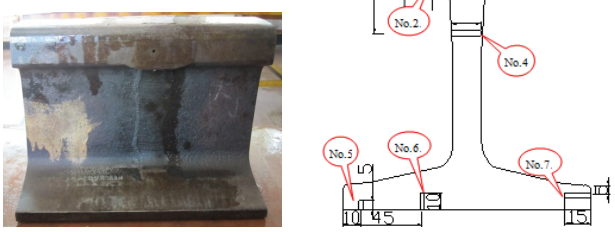


Fig. 5. Test specimen and defect size

Instrument debugging

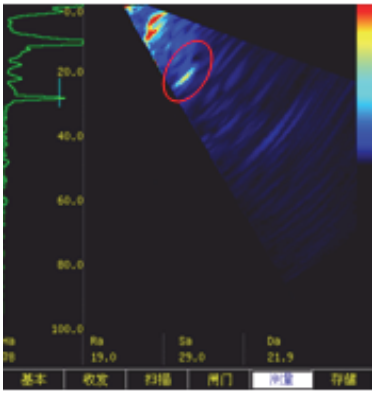
During ultrasonic phased array scanning gas pressure welding, adjust transmitted pulse width to 200ns, repeat frequency to 1500Hz, and sectorial scan angle from 30 ° to 70°. There is no uniform ultrasonic phased array inspection

gas pressure welding standard to be referred now. Refer to conventional ultrasonic pulse emission testing, adjusting the speed of sound and zero vertical to calibrate the phased array instrument.

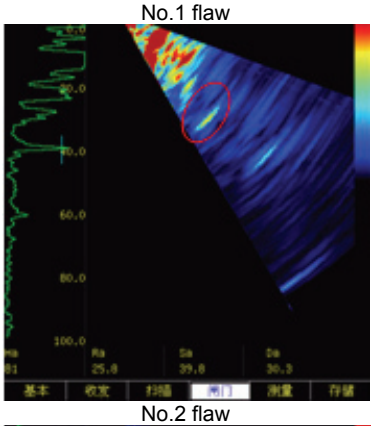
Experimental results and analysis

Phased array sector scanning

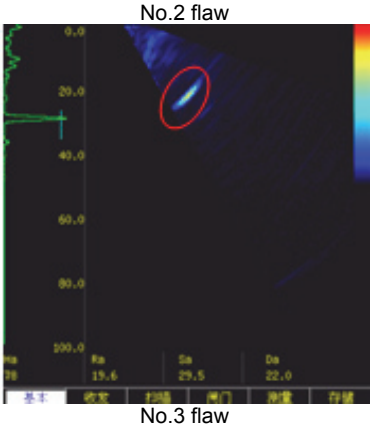
According to weld railway industry detection standards for the gas pressure welding, respectively testing the rail head, rail web and rail base of specimen with the sensitivity of various regions.



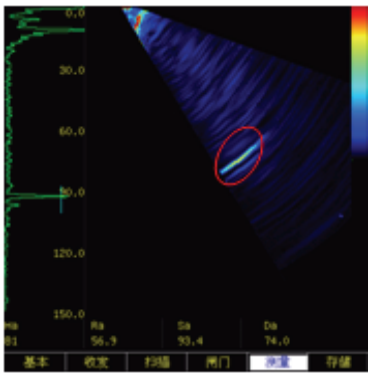
No.1 flaw



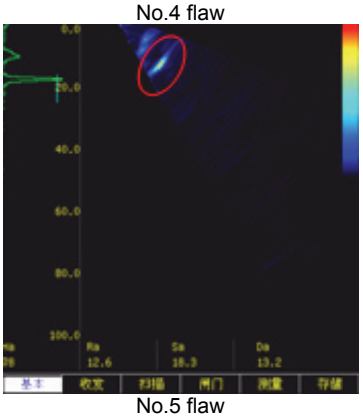
No.2 flaw



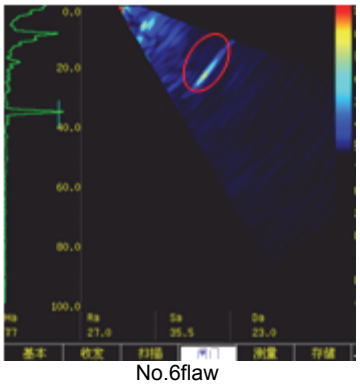
No.3 flaw



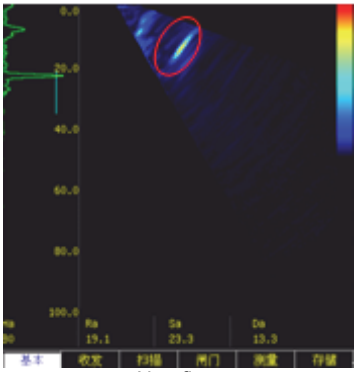
No.4 flaw



No.5 flaw



No.6flaw



No.7flaw

Fig. 6.Phased array sector scanning result

During the sectorial scanning, put the 16 crystals array S-probe on the rail tread to test the flaws in rail head and rail web, on the rail base top slant surface to test the flaws in rail base. For the defects close to the top of weld need to use the second wave scanning, the defects close to the bottom of weld need to use the first wave scanning. Used wave pattern is transverse wave. The phased array sectorial scan results as shown in Figure 6.

All figures in this paper, defects images marked by red circles, the left side of the figure corresponds to the A scan pulse.

Phased array linear scanning

During the linear scanning, similar to the placement of the probe during sectorial scanning, put the 64 crystals array L-probe on the rail tread to test the flaws in rail head and rail web, because of the big size of the probe, phased array linear scanning for rail base has not been carried out. Because of the probe size can cover the whole weld area, probe don't need to move in the scanning process. Phased array linear scanning uses longitudinal wave, which transmit straight acoustic beam to detect the weld defects of horizontal direction only. Phased array linear scanning result of the No.4 flaw as shown in Figure 7.

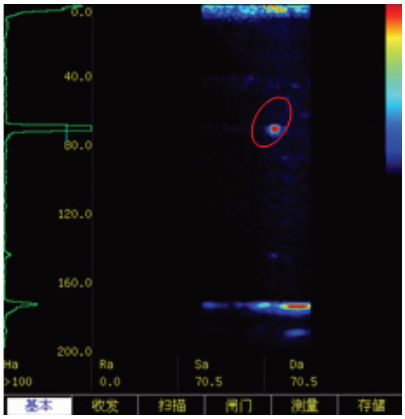


Fig. 7. Phased array linear scanning result of No.4 flaw

Experimental Analysis

The results show that artificial defects in a given location can find obvious defect image and verify the feasibility of ultrasonic phased array inspection experimental for gas pressure welding. In figure 5 and 6, the flaw imaging is clearly without interference noise, all of the images have high signal-to-noise ratio, and also defects in the image always have good reproducibility. From the test result images, we can easily found ultrasonic phased array's result is different from the A wave figures which get from conventional ultrasonic testing. The image of phased array contains abundant information about defects, expounding the defect location quite well, the location of defects in the weld appeared relatively straightforward, which is benefit for the discovery and identification of defects.

What's more important, the detection speed is fast .During ultrasonic phased array scanning, flexible control the beam scan angle through phased array scanning, with high detection speed and high efficiency, not need to use different inspection angle property of probes for different detecting regions, also, probe position does not require frequent movement in the process of scanning. Scanning process has characteristics of scanning flexibility and simple operation.

Conclusions

By the reasons of technology complexity and high input costs, the development of domestic phased array ultrasonic instruments in the area of industrial has been not involved. Using the phased array instrument CTS-602 which is the first phased array ultrasonic flaw detector made in China, by determining the experimental parameters and a reasonable testing program, to detect gas pressure welding of rails by the technology of ultrasonic phased array. Experimental results show that phased array inspection for gas pressure welding has the characteristics of scanning flexibility, high detection speed, high efficiency, excellent performance of repeated and good effect of imaging, etc. Compared with conventional testing of gas pressure welding by the single probe and double probes, the technology of ultrasonic phased array has outstanding technical advantages.

Acknowledgment

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