Research on Ultrasonic Phased Array Detection Technology for Internal Defects of Automobile Ductile Iron Components Based on Computer Technology

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Abstract. With the rapid development of automobile industry, ductile iron component has become one of the most important components, which is the core components in many aspects, such as engine crankshaft, wheel hub, etc., which will be subject to extremely complex loads. Therefore, the crankshaft R region is particularly prone to fatigue cracks, which requires us to continuously strengthen the internal defect detection technology. With the development of detection technology, conventional ultrasonic technology has been unable to meet the needs of society. Through electronic scanning and acoustic beam deflection focusing, we gradually improve the Ultrasonic phased array detection technology (hereinafter referred to as UPADT), which can better realize the detection of automobile ductile iron components. UPADT is a kind of ordered excitation to the beam element, which can realize the deflection and focusing of the sound beam [1]. By combining sector scanning, electron scanning and DDF, we can achieve more beam incident modes, which will have faster detection speed and more accurate sensitivity.

Keywords: Automotive Ductile Iron Components, Internal Defects, UPADT

1. Introduction

High quality carbon structural steel has many characteristics, such as good plasticity, which will be easier to draw, punch, extrude, forge and weld. This paper collects the detailed data of ductile iron casting production in China, with a total production of 49.35 million tons in 2018. This paper lists the output of castings of different materials in recent years, as shown in Table 1. Therefore, ductile iron material has been applied to a variety of fields, such as automobile, high-speed train, large ships and other manufacturing industries. However, with the improvement of people's requirements for safety, people put forward higher requirements for the quality of parts, which requires us to carry out Nondestructive testing (hereinafter referred to as NT). Through non-destructive testing, we can eliminate the unqualified products with internal defects, which will ensure the product quality. With the rapid development of science and technology, people have higher and higher requirements for NT of automotive ductile iron components. Therefore, UPADT has become the most important detection method, which can be more sensitive to find out the internal defects of components [2]. Therefore, NT
has become an important process in parts testing, which directly affects the service performance and safety performance of the machine.

Table 1. Output of castings of different materials (ten thousand tons)

| Year | Grey cast iron | Ductile iron | Malleable iron | Cast steel |
|------|----------------|--------------|----------------|-----------|
| 2013 | 2055           | 1160         | 60             | 550       |
| 2014 | 2080           | 1240         | 60             | 550       |
| 2015 | 2020           | 1260         | 60             | 510       |
| 2016 | 2035           | 1320         | 60             | 510       |
| 2017 | 2115           | 1375         | 60             | 555       |
| 2018 | 2065           | 1415         | 60             | 575       |

2. Basic principle of UPADT technology

2.1. Principle of ultrasonic testing

In the industrial field, ultrasonic can be used for non-destructive evaluation (NDE) of materials and structures, which has more and more applications. Through ultrasonic testing, we can inspect the car more quickly and safely, which has become the most commonly used tool in the industrial field. In industrial testing, ultrasonic testing is generally the interaction between ultrasonic and the workpiece to be tested, and the analysis of glory reflection wave, transmission wave and scattering wave. We can realize a variety of tests on the workpiece to be tested, including macro defect detection, geometric feature measurement, organizational structure and mechanical properties change, etc. Ultrasonic testing technology is an indirect detection technology, which can detect the output signal is mostly voltage time domain signal [3]. By generating and receiving sound energy through complex conversion, we can detect it, as shown in Figure 1. Ultrasonic transducers are usually made of piezoelectric materials with piezoelectric effect, which can convert electrical signals into sound waves of mechanical motion. When the transducer receives the excitation of electrical signal, the device will produce piezoelectric effect, which will generate an acoustic pulse in the form of sound wave, as shown in Figure 1 (a). When the acoustic pulse strikes the spherical reflector as shown in Figure 1 (b), the acoustic wave will emit and reflect at the interface. Therefore, the sphere will scatter the reflector in all directions.

Figure 1. The principle of ultrasonic testing.

2.2. Principle of ultrasonic testing

The piezoelectric effect of ultrasonic transducer has become the most widely used technology in industrial NT technology, as shown in Figure 2. The working principle of conventional ultrasonic testing is as follows. By applying high-frequency electric pulse generated by ultrasonic instrument to
the transducer, we can excite the piezoelectric wafer in the transducer to vibrate. Therefore, ultrasonic transducer can emit ultrasonic wave through piezoelectric effect, which will spread to the workpiece at a certain speed. When the discontinuity is encountered, one part of the sound wave is reflected back and the other part continues to propagate forward. When it comes to the bottom of the workpiece, the sound wave is also reflected back [5]. When the discontinuity defect and the sound wave reflected from the bottom surface are received by the transducer, we can convert the mechanical sound wave into electric pulse through the piezoelectric chip. When the transmitted wave (T), defect echo (f) and bottom echo (b) are amplified by the instrument, we can display them on the fluorescent screen of the instrument. In ultrasonic flaw detection, we can get the velocity of sound wave in the workpiece and the return time of defect pulse, which is easy to calculate the distance between the transducer and the spherical reflector (or discontinuous defect). By moving the single chip transducer, we can change the physical position and direction, which can obtain sufficient data information. Through the single chip transducer, we can carry out the mechanical scanning imaging method, which will cost more time. Therefore, the UPADT will be more effective. Among them, the acoustic beam can be manipulated by electronic components, which can use electronic scanning instead of conventional ultrasonic mechanical scanning [4].

Figure 2. Schematic diagram of ultrasonic flaw detection.

3. UPADT method

3.1. Basic principles
The concept of UPADT comes from phased array radar, which is mainly used in the field of high-resolution medical imaging. Compared with the conventional ultrasonic testing technology, UPADT technology mainly uses the array transducer with multiple array elements, which can rely on the computer to control the ultrasonic emission time of each array element. In this way, we can control the deflection and focusing of the synthesized beam of each array element in the sound field, and control the receiving [6]. The time when each element in the transducer array can receive the echo signal, which is a detection technology for deflection, focusing and imaging detection. By electronic means, we can control the beam deflection angle, focusing depth and so on, which can be continuously adjustable in a certain range.

3.2. Emission of UPADT
The theory of UPADT is mainly based on Huygens Fresnel principle. When the transducer elements are excited by the same frequency pulse signal, the emitted sound wave is coherent wave, which will produce interference phenomenon. The amplitude of sound pressure at some points in space will be enhanced by the superposition of sound waves in phase, and the amplitude of sound pressure at other points will be weakened by the cancellation of sound waves in phase, which will form a stable
ultrasonic field. In phased array, ultrasonic transducer can include a group of small piezoelectric elements (array elements), which can be independently controlled and receive feedback signal. If the same control signal is input to each element, the driving electric pulse will be in step, which will reach each piezoelectric element at the same time. Each element in phased array can be regarded as a point wave source and emit spherical wave [7]. The superposition of spherical waves will form traveling wave pulses, as shown in Figure 3.

Figure 3. There is no relative delay between UPADT elements.

3.3. Deflection and focusing of sound beam
Except for the area very close to the phased array, the sound beam generated by the transducer array is similar to that generated by the single chip transducer in other areas. By changing the relative delay $\Delta T_i$ of driving pulse signal between different elements in the array (called delay law), we can make phased array produce angular deflection of acoustic beam through electronic components, as shown in Figure 4 (a). At the same time, through the nonlinear delay rule, we can make the phased array produce sound beam focusing, as shown in Figure 4 (b). Through the complex combination of delay law, we can realize the deflection and focusing of sound beam. Phased array can realize flexible control of sound beam characteristics through electronic delay, which will improve the detection speed and reliability of ultrasonic detection.

Figure 4. Deflection and focusing of sound beam.

3.4. Receiving of UPADT
When the ultrasonic synthetic beam emitted by the excitation array element propagates in the workpiece, it will be reflected back if there are discontinuities or interfaces. At this time, the transducer elements can receive the echo signal, which will cause the relative delay of each element. At the same time, we can change the characteristics of the received signal of the phased array, as shown in Figure 5 (a), which will lead to the variable delay of the waveform arriving at the array at a specific angle. When it impacts each element in the phased array, we will generate a series of electric pulse signals [8-9]. When the incident wave front is curved, the delay time can still adjust and stack the signals received by each array element, which will be equivalent to the signals received by the conventional single crystal focusing transducer, as shown in Figure 5 (b).
4. UPADT results of internal defects of automobile ductile iron components

4.1. Real time flaw detection
The real-time flaw detection starts automatically, as shown in Figure 6.

![Figure 6. Schematic diagram of flaw detection results.](image)

4.2. Experimental results and analysis
This paper is based on the artificial simulation defect experiment under the UPADT system, which automatically generates the flaw detection report [10]. The experimental results of artificial defect sensitivity test are shown in Table 2.

| Defect type                  | Defect size | Detection sensitivity | Stability test |
|------------------------------|-------------|-----------------------|----------------|
| Axial flat bottom hole       | 2mm X 80mm  | 58 dB                 | 57 dB          |
| Axial flat bottom hole       | 2mm X 90mm  | 58 dB                 | 58 dB          |
| Axial flat bottom hole       | 2mm X 100mm | 60 dB                 | 59 dB          |

5. Conclusion
UPADT technology can be applied to NT of automobile ductile iron components, which can detect large castings with complex shape and large wall thickness [11]. Through UPADT technology, we can comprehensively and accurately monitor and evaluate defects, which has higher sensitivity and stability. Through the phased array method, we can clearly distinguish the adjacent small defects, which can more accurately evaluate the defect level.
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References
[1] Chen Changhua, Tang Zhigui, Chen nengjin, et al. UPADT analysis of train wheel defects [J]. Physical test, 2012,30 (1): 34-39.
[2] He Feng, Liu Enkai. Application of phased array ultrasonic testing technology in penetration weld inspection of nuclear power equipment [J]. Pressure vessel, 2015,32: 63-69.
[3] Jiang Yuliang, Xu Demin, Zhang Wei, et al. UPADT of ductile iron castings [J]. Modern cast iron, 2014 (4): 22-27.
[4] Jin Shijiu. Development and application of UPADT [J]. Journal of electronic measurement and instrument, 2014, 28 (9): 925-934.
[5] Song Zhiming, Wang Li, Zhou Xiaohong, et al. Sound field simulation in UPADT technology [J]. Piezoelectric and acoustooptic, 2012, 34 (4): 565-570.
[6] Wang Xingming, Guo Yaohong, Zhu Qingyou, et al. Research progress in NT of composites [J]. FRP / composites, 2012 (Supplement 1): 261-265.
[7] Xie Congzhen. Internal defects detection of composite insulator by phased array ultrasonic method [J]. Chinese Journal of electrical engineering, 2012 (1): 63-68.
[8] Yong Qilong, Dong Han, Liu Zhengdong, et al. Development of structural steel for advanced mechanical manufacturing [J]. Metal heat treatment, 2010,35 (1): 2-8.
[9] Yu Shiming, Luo Gengsheng, Wang Huaming, et al. UPADT detection of high pressure nitrogen storage tank [J]. NT, 2010,32 (4): 274-276.
[10] Zhong Zhimin, Mei Desong. Development and application of UPADT technology [J]. NT, 2002, 24 (02): 69-71.
[11] Zhu Xuegeng, Dong Shiyun, Xu Binshi. Study on phased array ultrasonic testing method for compressor impeller root defects [J]. China Mechanical Engineering, 2015,26 (18): 2436-2441.