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Study on Signal De-Noising for Multi-Channel Automatic Ultrasonic Testing System

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Abstract

To ensure the quality of thick-walled seamless steel pipe, the defects in thick-walled seamless steel pipe should be detect. This paper has developed PC-based microcomputer water immersion, digital multi-channel automatic ultrasonic testing system based on the principle of ultrasonic flaw detection of thick-walled seamless steel pipe. The hardware and software of this detection system were designed. To improve detection efficiency and accuracy, all sorts of effective anti-interference measures were proposed. They could effectively remove interference signals in ultrasonic echo signal by analyzing interference source and dissemination way of automatic ultrasonic flaw detection system for small-diameter steel pipe with thick wall. An improved wavelet threshold was proposed to remove mixed noise in the echo signal to improve the echo signal-to-noise ratio at the same time. Experimental results show that the ultrasonic flaw detection system can achieve defect detection of the Small-Diameter Steel Pipe with Thick Wall, the wavelet threshold de-noising method can effectively remove mixed noise in the ultrasonic echo signal and the echo signal-to-noise ratio was improved greatly.

Keywords: *Ultrasonic Testing, Thick-walled Testing, System Design, signal de-noising, wavelet*

1. Introduction

Isostatic pressing technology is the isostatic pressing equipment and its'application. It can thoroughly solve the shortcomings that the regular production is unable to overcome and increase the excellent properties of materials and products. Isostatic pressing technology is a substantive breakthrough for traditional powder metallurgy sintering process technology .It is a prior technology for modernization of national defense and the rapid development of science and technology for high temperature alloy powder, high strength composite materials, new type of engineering ceramics, superconducting materials, optical materials and other high-tech materials [1].

The weakest part in the isostatic press is high-pressure seamless steel tube, so it is most important to make the high-pressure seamless steel more reliable.

In order to ensure the safety of the product, the product production enterprise must test the seamless steel tube by using the national standard. Many flaws or cracks detects techniques have been applied into our industry, such as the X-rays [2] ,Ultrasonic inspection, Radiographic inspection, Magnetic particle inspection, penetrant inspection, acoustic emission inspection ,magnetic flux leakage inspection and so forth [3].

Now, the main flaw detection methods for seamless steel tube, using under high temperature and high pressure, are eddy current testing and ultrasonic testing. The ultrasonic detection method has the feature of wide scope, accurate deep defects, high detection sensitivity, low cost, quick, harmless to the human body and so forth [4].From

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reference 2 to 6,the authors have used the ultrasonic defects detecting method to detect the crack [4-8].

Isostatic press seamless steel tube is the thick wall pipe, of which the t/D ratio is more than 0.26. Defects inspection for thick-walled seamless steel pipe in the domestic is a difficult item. This paper has developed a PC-based microcomputer water immersion, digital multi-channel automatic ultrasonic testing system based on the principle of ultrasonic flaw detection of thick-walled seamless steel pipe, The hardware and software of this detection system were designed. To improve defect recognition's efficiency and accuracy, all sorts of effective anti-interference measures were proposed by using the wavelet theory.

2. Overall Design of System

2.1. Working Principle of the System

In order to achieve the automation of system testing, we use water immersion inspection method, which using water as coupling agent. The probe is in the water, so the ultrasonic reflect back into the steel tube at the interface and mode conversion of wave type of ultrasonic happens at the same time. Choose stationary probe scanning method, steel pipe has spiral feed movement. This scanning method can reduce the number of mechanical transmission mechanism. Using sound-light alarm system, the alarm system goes off immediately when detects defects, and delay the dot mark. Dot marking system adopts pneumatic type, which can be sprayed on the steel pipe.

Multi-channel detection system adopts the basic principle of time sharing mechanism. Under the control of the synchronous circuit, multiple channels of probe points work in turn. Echo signal of each channel which under the control of synchronous programming and multi-channel switch goes into the high-speed signal acquisition system at different time point. After A/D conversion, the analog signals turn into digital signals. Digital signal after filtering communicate with the upper PC. The upper PC analyzes digital signal phase and amplitude characteristics. According to the set alarm threshold, signal cross the threshold in the echo data will be stored to the cache and generate alarm signal. After receipt of the signal, detection software will stored echo waveform data in the computer hard disk, and add the defect records in the database. After the workpiece inspection, system will automatically generate a inspection report, we can see defect distribution from the report.

2.2. Design of the Hardware

System overall design is based on PC platform, four-channel PR401 ultrasonic interface card, ultrasonic TCF6401B sequential control filter interface card and A/D data acquisition card communicate with PC through ISA bus. Detection system structure as shown in Figure 1.

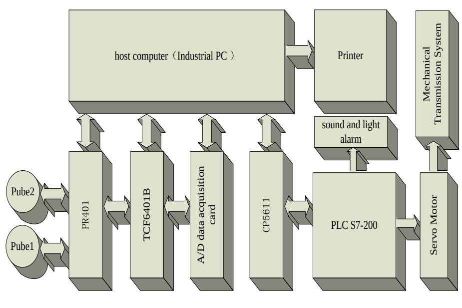

Figure 1. Ultrasonic Automatic Testing System Structure Diagram

S200 series PLC of Siemens communicate with upper PC by CP5611. The upper computer can control servo motor with sound and light alarm status, servo motor drive the whole transmission system to achieve the uniform spiral movement of steel pipe, then the probe can realize comprehensive dynamic scanning.

2.3. Detection System Software Design

Main function modules of the software include: echo acquisition, preprocessing module, a defect diagnosis module, echo display module, PLC control module, report management module, and defect management module *et. al.*, software flow chart are shown in Figure 2, [12].

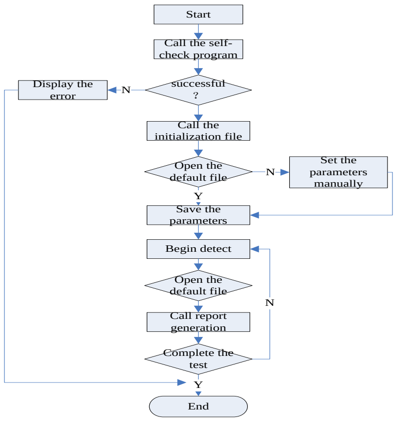

Figure 2. Software Flow Chart

3. Echo Signal Processing

3.1. Wavelet Transform De-Noising

Basic ideas of wavelet de-noising can be summed up in Figure 3: noise signal is decomposed into multi-scale using the wavelet transform with binary wavelet transform type (such as Daubechies, iterative method based on discrete filter structure of tight set standard orthogonal wavelet function. The wavelet function with symmetry and regularity, which avoid moving signal phase and the reconstruction of the cancellation to deal with the noise to achieve good smoothing effect is very useful), then remove coefficients of noise in each scale belongs to the noise, maintain and enhance coefficients of signal belongs to the wavelet, finally reconstructed signals after wavelet de-noising [13]

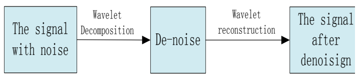

Figure 3. The Wavelet De-Noising Block Diagram

$\forall f(t) \in L^2(R)$, $f(t)$, continuous wavelet transform (sometimes referred to as the integral wavelet transform) is defined as:

$$WT_f(a,b) = |a|^{-1/2} \int_{-\infty}^{\infty} f(t) \overline{\psi\left(\frac{t-b}{a}\right)} dt, \quad a \neq 0 \tag{2}$$

Where $\psi_{a,b}(t) = |a|^{-1/2} \psi\left(\frac{t-b}{a}\right)$

To make the inverse transformation when $\psi(t)$ satisfies conditions allow, the inverse transformation is

$$f(t) = C_{\psi}^{-1} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \psi_{a,b}(t) WT_{f}(a,b) db \frac{da}{|a|^{2}} \tag{3}$$

The constant C_{ψ} limits the function ψ that can be used as "base wavelet or mother wavelet"

3.2. Wavelet Threshold De-Noising

Wavelet transform has a strong correlation. It can make the energy of the signal in wavelet domain centralized in some large wavelet coefficients. And the noise energy is distributed in the wavelet domain. Therefore, after wavelet decomposition, the wavelet coefficient of signal amplitude is greater than the coefficient of amplitude noise. Using threshold method can keep the signal factor, and make the most noise coefficient decreases to zero [14]. Wavelet threshold de-noising method of shrinkage process is: decompose the noise signal on each scale wavelet, set a threshold, the amplitude is lower than the threshold of wavelet coefficients are set to 0, wavelet coefficients higher than the threshold are completely retained, or make a corresponding "shrinkage" processing. Finally inverse wavelet transform will reconstruction the wavelet coefficients obtained by de-noising signal.

3.2.1. Threshold Function: The commonly used threshold functions are hard threshold function and soft threshold function. Hard threshold function is a good way to retain local characteristics, such as signal edge, *etc.,* Soft threshold de-noising processing adopt smooth processing to make the edge character of ultrasonic echo signal fuzzy even disappear completely. In order to overcome this defect, this paper proposes a semi-soft threshold function, as shown in Figure 4. It can balance the advantages of soft threshold and hard threshold method, the expression is:

$$\eta(w) = \mathrm{sgn}(w) \frac{T_2(|w| - T_1)}{T_2 - T_1} I(T_1 < |w| < T_2) + wI(|w| > T_2) \tag{4}$$

Where $0 < T_1 < T_2$ 。

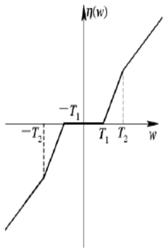

Figure 4. Semi-Soft Threshold Function

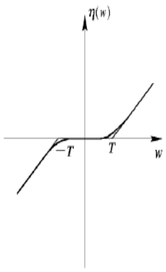

Figure 5. Improved Soft Threshold Function

On the basis of soft threshold it can be improved to make it with a higher order, as shown in Figure 5. As you can see it has a smooth transition between continuous features in the noise (wavelet coefficients) and useful signal (the wavelet coefficient), which is more accord with natural signal. Its expression is:

$$\eta(w) = \begin{cases} w + T - \dfrac{T}{2k+1} & w < -T \\ \dfrac{1}{(2k+1)T^{2k}} w^{2k+1} & |w| \le T \\ w - T + \dfrac{T}{2k+1} & w > T \end{cases} \tag{5}$$

3.2.2. Threshold Estimation: VisuShrink method (or the unified threshold de-noising method) was proposed by Donoho in 1994. It is aimed at independent multidimensional normal variable joint distribution, concluded in dimension tends to infinity, under the limit of the maximum estimator of the optimal threshold. The choice of the threshold needs to meet:

$$T = \sigma_n \sqrt{2 \ln N} \tag{6}$$

Where, σ_n is the noise standard deviation and N is the length of the signal. Donoho prove that when the estimated signal belongs to Besov set, under a lot of risk function, it can obtain the approximate optimal de-noising risk. The unity threshold method of Donoho is less ideal in the practical application which produced serious killing phenomenon. The threshold calculation method based on unbiased estimation was put forward in 1997 by Janse.

Risk is defined as a function: $R(t) = \left\| \hat{f} - f \right\|^2 / N$ 。 Due to the orthogonality of the wavelet transform, the risk function can be also written in the wavelet domain $R(t) = \left\| \eta_t(Y) - X \right\|^2 / N$ 。

If we take $R(t) = \left\| \eta_t(Y) - Y \right\|^2 / N$, then

$$\begin{aligned} ET(t) &= \frac{1}{N} \left\| \eta_t(Y) - Y \right\|^2 = ER(t) + \sigma_n^2 - \frac{2}{N} E < V, \eta_t(Y) > \\ &= \frac{1}{N} E\left[\left\| \eta_t(Y) - X \right\|^2 + \left\| X - Y \right\|^2 + 2 < \eta_t(Y) - X, X - Y > \right] \end{aligned} \tag{7}$$

The risk function can be expressed as：

$$\begin{aligned} ER(t) &= ET(t) - \sigma_n^2 + \frac{2\sigma_n^2}{N} \sum_{i=1}^{N} I(|Y_i| > t) \\ &= \frac{1}{N} \sum_{i=1}^{N} (|Y_i| \wedge t)^2 + \sigma_n^2 - \frac{2\sigma_n^2}{N} \sum_{i=1}^{N} I(|Y_i| < t) \end{aligned} \tag{8}$$

where $\wedge$ is indicative function, I means take the smaller one. So, the best threshold selection can be obtained by minimizing the risk function, which is:

$$t^* = \arg\min_{t>0} ER(t) \tag{9}$$

4. Experiment

Thick wall tube of water immersion ultrasonic automatic testing system is made up of a multi-channel ultrasonic flaw detector and a mechanical transmission system, the system diagram is shown in Figure 6, where :1 - control cabinet, 2 - liquid crystal display, 3-control button, 4-discharge roller table, 5 - the injector, 6 - lateral wounded probe, 7 – tank, 8 - longitudinal probe, 9 - steel tube feeding unit, 10- feed roller table,11- DC motor, 12-storage tank, 13- inspection work platform, 14-control bus. Using the above proposed threshold function to de-noising ultrasonic echo signal. The experiment subject is a $\Phi 50 \times 12\ mm$ steel pipe. Ultrasonic probe is 5 MHZ water immersion focusing probe. We adopt the pulse reflection type detection method and the sampling frequency is 100 MHZ. The experiment was performed with a non-defect, a longitudinal and a transverse defected steel pipe respectively, the results are shown in Figure 7-Figure 11.

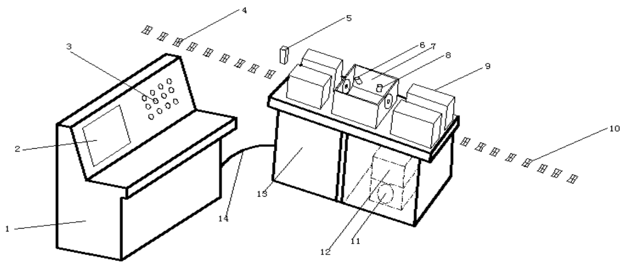

Figure 6. Thick-Walled Seamless Steel Pipe Automatic Ultrasonic Flaw Detection System

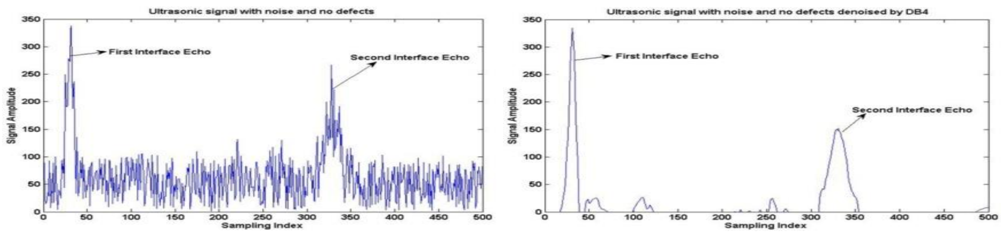

Figure 7. Processing the Signal Collected from the Small-Diameter Steel Pipes with Thick Wall (Φ50x12) (Left) the Original Signal without Flaws; (Right) the Processed Signal De-Noised By DB4

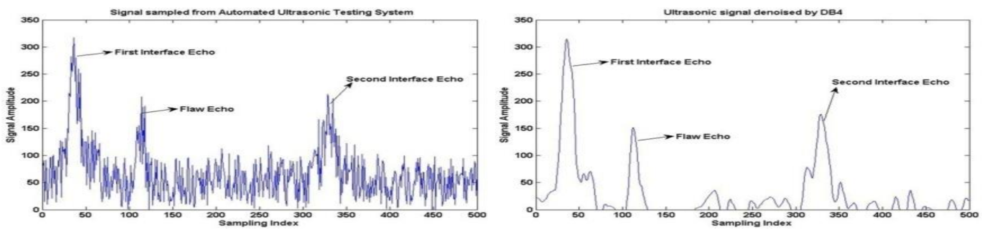

Figure 8. Processing the Signal Collected from the Small-Diameter Steel Pipes with Thick Wall (Φ50x12) (Left) the Original Inside-Wall Flaw Signal Using Transverse Wave; (Right) the Processed Signal De-Noised By DB4

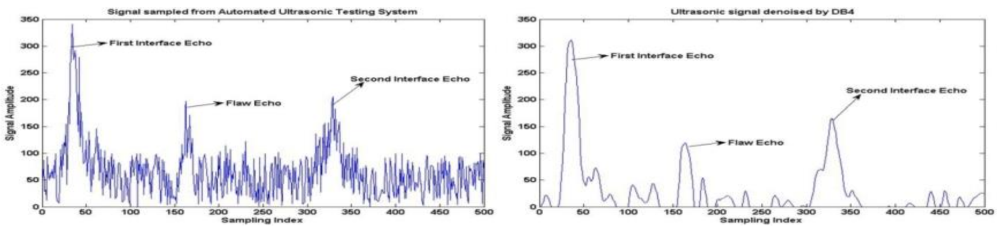

Figure 9. Processing the Signal Collected from the Small-Diameter Steel Pipes with Thick Wall (Φ50x12) (Left) the Original Outside-Wall Flaw Signal Using Transverse Wave; (Right) the Processed Signal De-Noised By DB4

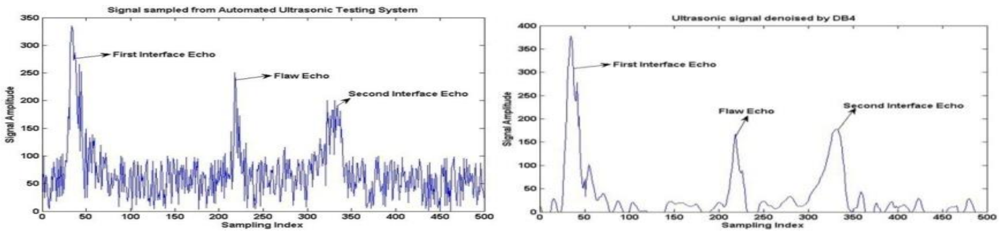

Figure 10. Processing the Signal Collected from the Small-Diameter Steel Pipes with Thick Wall (Φ50x12) (Left) the Original Inside-Wall Flaw Signal Using Longitudinal Wave; (Right) the Processed Signal De-Noised By DB4

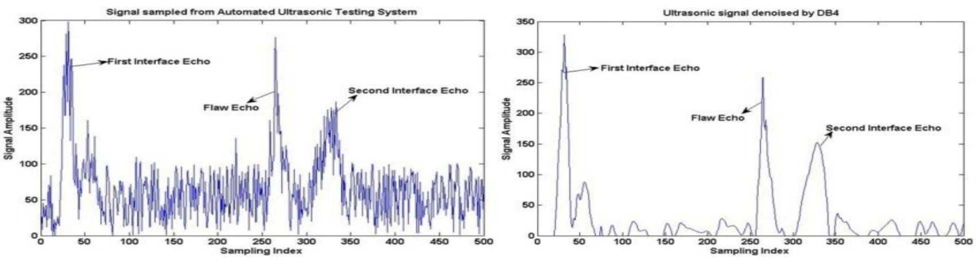

Figure 11. Processing the Signal Collected from the Small-Diameter Steel Pipes with Thick Wall (Φ50x12) (Left) the Original Outside-Wall Flaw Signal Using Longitudinal Wave; (Right) the Processed Signal De-Noised By DB4

5. Conclusion

This paper develop a set of PC based thick wall seamless steel tube water immersion, fully digital multi-channel automatic ultrasonic testing system based on the analysis of ultrasonic testing principle of the thick wall seamless steel tube, and using an improved wavelet threshold de-noising method to eliminate the noise in the mixed echo signal and improved echo signal-to-noise ratio at the same time.

1) Using double channel pulse reflection type vertical wave probe test thick-walled tube longitudinal and transverse defects, and the scanning mode select probe fixed and steel pipe move forward in spiral;

2) Experiments show that, in the system, a scan, echo display and ultrasonic processing functions can meet the requirements. The sensitivity of circumferential ≦ 4 db, poor SNR ≧ 8 db, the system meet the design indexes such as stability.

3) the ultrasonic flaw detection system can realize path defect inspection of thick wall steel pipe. Before using the wavelet threshold de-noising ultrasonic, echo signals can be seen clearly in ultrasonic flaw detection with a lot of noise, which seriously affect the path of thick wall steel tube defect discrimination and analysis making the signal's SNR greatly reduced which is likely to cause defects miscalculation or misstatement.

4) The ultrasonic echo signals, after wavelet threshold de-noising and wavelet threshold de-noising method, can effectively remove the mix-noise in the ultrasonic echo signal and greatly improve the echo signal-to-noise ratio. In the echo signal of an interface and the secondary interface wave, defect is clearly visible, which reduces the incidence of defects misstatement or miscalculation.

Acknowledgments

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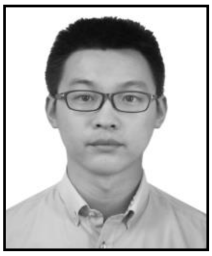

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