Study on Ultrasonic Detecting Technology of Profiled Component

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Abstract: - The profiled component has some structural features, such as thin wall, small diameter and corner angle on inner wall. The features make it very difficult to detect the profiled component with non-destructive examination method. According to the principle of ultrasonic creeping wave, a grouped ultrasonic detecting method is put forward to detect the standard defects in inner and outer of profiled component. Based on comparing defect echo with inner edge wave, feature extraction method of two characteristics of amplitude and time is put forward to extract defects and to eliminate the interference of inner edge wave. In order to overcome the one-sidedness disadvantage of single probe data, data fusion technology of synthesis local decisions of three probes is used to determine defects, which improves the accuracy of defect judgement. Three characteristic values of period, duration time and amplitude of echo signal are used to comprehensively evaluate the defect type. The testing results indicate that the detection method and signal processing method can meet the application requirements of accuracy and reliability, and it would have good application foreground for on-line detection.

Key-Words: - profiled component; creeping wave; inner edge wave; time characteristic; amplitude characteristic; data Fusion

1 Introduction

Compared with the structure of a single component such as a plate, a rod and a tube, profiled component is complex component composed of two or more single components. It generally has more angles and complex geometry shape, which brings more difficulties to ultrasonic detecting. Focusing method using immersion focusing and plate wave are applied to detect thin-wall tubes with small diameter[1-7]. But arc troughs of the profiled component make its structure more complex than ordinary thin-wall tubes with small diameter and add its detecting difficulty with ultrasonic method[8][9]. Single detecting method is difficult to make full cover the profiled component because of much more jamming signals. At present, the main method to detect profiled component is grouped ultrasonic detecting method, in which a probe only detects a part of the component, thus multi-beam ultrasonic wave generated by multi probes could cover entire component to decrease the undetected[10][11]. Various profiled component has different structural characteristics, so its detecting principle and inspecting stage are different, proper method can be used only according to the specific structure of profiled component.

Besides, binding sites of the basic structure can form edges and corners, a strong jamming signal can be reflected there in ultrasonic testing. It is very difficult to distinguish flaw signal form reflecting signals. Therefore, the profiled component detection has technical difficulty in ultrasonic non-destructive testing filed. Processing the data of each probe respectively has not played the advantage of data fusion of multi probes.

According to the structural features of detected component, the ultrasonic creeping wave is used to detect the traverse and longitudinal flaws of profiled component in this paper. At the same time signal recognition method of extracting time and amplitude characteristic value eliminates the interference of inner edge wave in flaw recognition. Data Fusion of three probes is processed for synthetic quantitative evaluation of flaws.

2 Detection Principle

2.1 Generation Condition of Creeping Wave

According to the geometry acoustics principle and Snell law, when ultrasonic longitudinal wave is incident from one medium to another medium surface at certain angle, reflection and refraction will occur, in the meantime wave mode will be converted. Refraction longitudinal wave and refraction transverse wave will be generated in the second medium, too. If incident wave velocity and reflected wave velocity meet the following relationship:

$$C_{1L} < C_{2T} < C_{2L} \quad (1)$$

C_{1L} is incident longitudinal wave velocity in the first medium, C_{2L} is refracted longitudinal wave velocity in the second medium, C_{2T} is refracted transverse wave velocity in the second medium.

That is to say that if ultrasonic wave is incident from medium with small medium sound velocity to medium with big sound velocity, the bigger incidence angle is, the bigger refraction angle is. When incidence angle $\alpha = \arcsin\frac{C_{1L}}{C_{2L}}$ is satisfied, the refracted longitudinal wave will propagate following the interface. The incidence angle at this time refers to as the first critical angle. It is generally acknowledged that when Incidence angle is equal to the first critical angle, creeping wave will be generated under the second medium surface as shown in Fig.1.

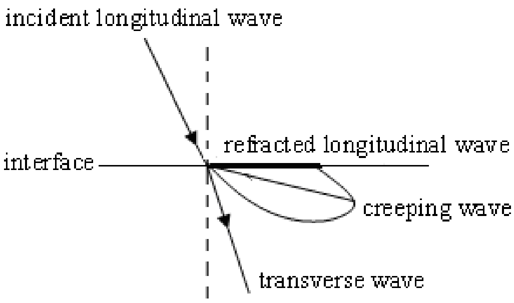

Fig.1 Generation condition of creeping wave

2.2 The Characteristics of Creeping Wave

When the incidence angle is equal to the first critical angle, refracted longitudinal wave will spread along the surface of the second medium. Due to the boundary conditions, the refracted longitudinal wave will continually radiate transverse wave when it spreads. The peak wave of transverse wave under medium surface which spreads between refracted longitudinal wave and transverse wave is called creeping wave, while the front wave of transverse wave is called bow wave. So the sound field near the surface of the second medium has the characteristic of the multi-wave-type.

When the incidence point is fixed, the radiant point of creeping wave is fixed, it continuously radiates outward near the incident point. While the radiant point of bow wave is not fixed, as creeping wave propagation it moves outward continuously from the point creeping wave locates. In addition, according to the theory of wave acoustics, the creeping wave is synthesized by the refracted longitudinal and transverse wave when the incidence angle is equal to the first critical angle. Particle vibration created by creeping wave is synthesized by longitudinal wave and transverse wave, so the particle displacement can be expressed as the following:

$$\vec{S} = \mathrm{grad}\vec{\Phi} + \mathrm{rot}\vec{\Psi} \quad (2)$$

$\vec{\Phi}$ and $\vec{\Psi}$ are potential function of refracted longitudinal wave and that of transverse wave respectively. The creeping wave has following characteristics[12-15]:

(1)Propagation speed of creeping wave is close to that of the refracted longitudinal wave, when other condition are the same, its speed and wave length are larger, so the surface scattering is relatively weak and creeping wave is not sensitive to surface roughness.

(2) Creeping wave is quickly attenuate after leaving the probe, so it is suitable for test the thin-wall component.

(3) The maximum amplitude direction of creeping wave has a small angle with the surface, and has relation to incidence angle. If probe frequency f = 1.8MHz, wafer diameter D = 18mm, distance to incidence point r = 150mm, the relation between refraction angle θ_{max} and incidence angle α on the water and steel interface is shown in Fig.2. From Fig.2 it is can be found that the bigger incident angle is, the bigger θ_{max} corresponding with primary petal is. Therefore, the direction of main energy of creeping wave in the inner material can be changed by adjusting incidence angle of longitudinal wave, which can improve the sensitivity of reflection echo signal.

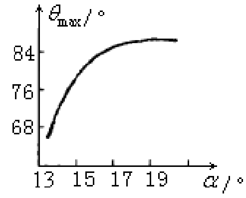

Fig.2 The relationship between refraction angle θ_{max} and incidence angle α

(4) The energy of creeping wave is concentrated mainly near the material surface, but the maximum value does not spread along the surface, it spreads at regular angle to the surface. So creeping wave can detect defects in near-surface region of material, the deepest detected distance is about 10mm to the surface.

3 Detection Scheme

3.1 The Structure of Profiled Component and Flaws

The structure of profiled component detected is shown in Fig.3. Its structure can be divided into three parts, the upper end is a section of thin-wall tube with six arc troughs on inner wall, the middle is a small diameter bar, and the lower end is a thin-wall tube thicker than the upper. The wall thickness of the upper end is less than 6mm, and the thickness of top of inner arc is only 4mm. So its structure has characteristics of small diameter, thin-walled, multi-edges and complex structure. Inner edge wave can be produced when ultrasonic wave is reflected by the edge of arc inner wall at the upper end of profiled component. It has has the characteristics of strong energy, period and it is not easy to be eliminated, which seriously interferes in recognition of flaw signal. To recognize flaw signal from the inner edge wave correctly is the difficulty studied here.

There are mainly cracks, inclusions, stomata and internal and external surface scratch marks in the profiled component. As a kind of pressure vessel, any flaw can affect its performance, so any flaw is not allowed existing in the profiled component.

In generally, the orientation of flaw in the pipe is divided into circumferential direction, radial direction, axial direction and irregular direction. The transverse flaw is vertical to axis, and the longitudinal flaw is parallel to axis. According to detection requirements and structural characteristics of profiled component, artificial flaws A, B and C are made in the component, as shown in Figure3. A is longitudinal flaw in the external surface, B is transverse flaw at the top of inner arc, C is transverse flaw in the external surface. The length, width and depth of the artificial defects are 10± 0.5mm，0.15±0.015mm and 0.15±0.015mm.

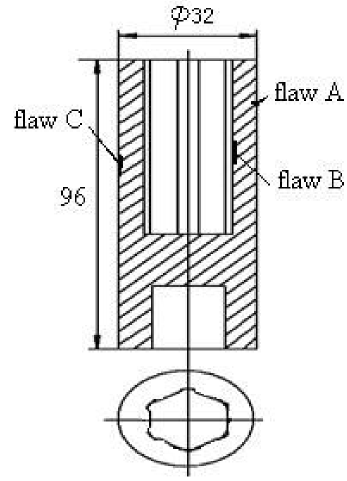

Fig.3 The structure of profiled component

3.2 Detection Method

According to the structural features of several kinds of flaws in the profiled component, thickness measuring probe T1, axial probe T2 and circumferential T3 are set to detect flaws in the profiled component, distribution of probes is shown as Fig.4. Probe T1 is 5MHz two-crystal thickness measuring probe. Pulse bottom wave reflection method is used to measure thickness of profiled component, as shown in Fig.5. Besides, it is used to detect the circumferential flaw such as separated layer in the wall of detected component. As the thickness of profiled component can occur in mutations where the flaw exists, which can be used to determine whether the flaw exists. Probe T2 is 5MHz point-focusing probe, immersion focusing method is used to detect the transverse flaw, as shown in Fig.6. Firstly adjust the incident angle to the first critical angle, creeping wave is stimulated in the wall of detected component. Adjust the incident angle again and change the main energy direction of creeping wave in order to maximum echo signal amplitude. Probe T3 is 5MHz line-focus probe, the same method of immersion focusing method is used to stimulate creeping wave, as shown in Fig.7. The main energy direction of creeping wave is changed through adjusting the incident angle. When echo signal amplitude is the biggest, longitudinal flaw defection is realized. When the profiled component is rotating, three-beam ultrasound waves generated by three probes overlap and coverage each other, which can cover the entire profiled component to effectively detect the presence of other flaws with irregular orientation.

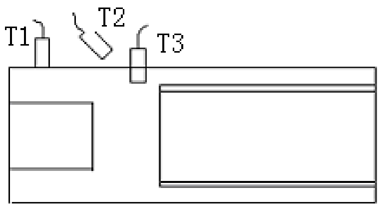

Fig.4 distribution of probes

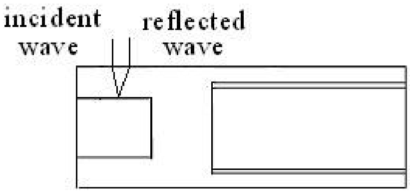

Fig.5 Two-crystal thickness measuring principle

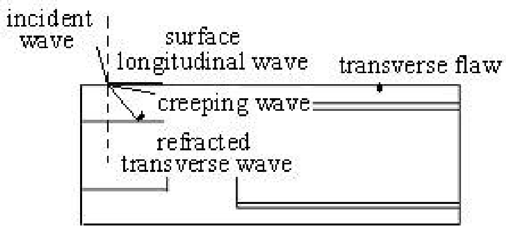

Fig.6 Detecting principle of the transverse flaw

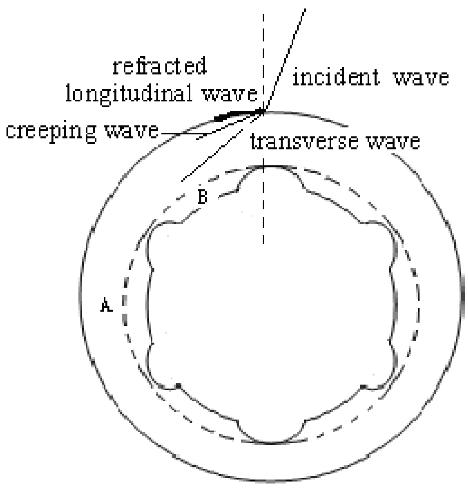

Fig.7 Detecting principle of the longitudinal flaw

4 Flaw Static Characteristic and its Processing Method

According to above detection method, typical flaw signals and inner edge wave can be got by home-made 8 channel digital flaw detector, which are shown in Fig.8. From the Fig.8 it can be seen that the amplitude of echo signals everywhere are strong enough and the signals have good resolution. The amplitude of echo signal is usually used to distinguish flaw signal in ultrasonic detection. But the amplitude difference between inner edge wave and flaw signal is not much great, only using amplitude characteristic can not eliminate the interference signal of inner edge wave. But they can be distinguished clearly from time difference relative to the water-steel interface echo. The time of flaw echo signal in the outside surface is the shortest, the time of inner edge wave is the longest and the time of flaw echo signal on the top of inner arc is placed in the middle. From material structure, the distance from surface to outside surface flaw is the nearest, that to the top flaw of inner arc takes second place and that to the inner arris is the farthest, so the time characteristic of echo signal can be extracted to distinguish whether the echo is flaw or not. In order to improve the accuracy of flaw judgment, two characteristic values of time and amplitude of echo signals are extracted in flaw judgment at the same time.

. The thickness of the top of inner arc is the minimum, so defect here is fatal. In order to ensure this defect is not undetected, the wall of profiled component can be divided into two parts A and B from the arc top according to acoustic distance, as shown in Fig.7. Two gates GATEA and GATEB are designed in the circuits. GATEA selects the echo reflected by the defect between the outer surface and the top of inner arc, and GATEB selects the echo reflected by the defect between the top of inner arc and internal surface. Timing relation between echo signals and gating signals are shown in Fig.9. In order to reduce the impact of the inner edge wave, the two part defect signals are dealt with separately.

To achieve above signal processing and online detection requirements, the circuits are designed, as shown in Fig.10. GATEA signal is generated by the trigger signal and echo reflected by the defect in range A, which controls the work of counter to extract the time characteristic from echo. At the same time, the amplitude characteristic of the echo is extracted by peak hold circuit and is read by A/D. GATEB signal is generated by the trigger signal and echo signal reflected by the defect in range B, which controls the work of counter to extract the time characteristic from echo. At the same time, the amplitude characteristic of the echo is extracted by peak hold circuit and is read by A/D.

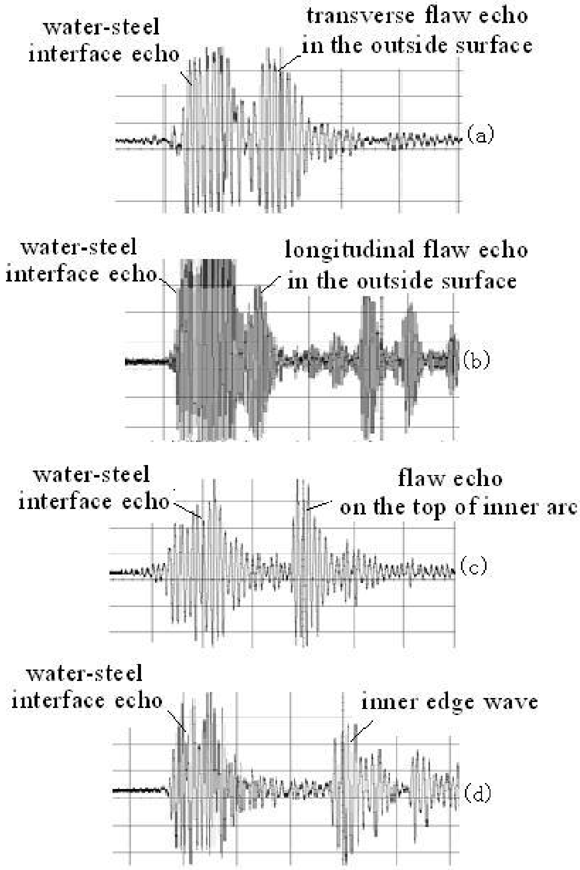

Fig. 8 Typical echo signal and inner edge wave

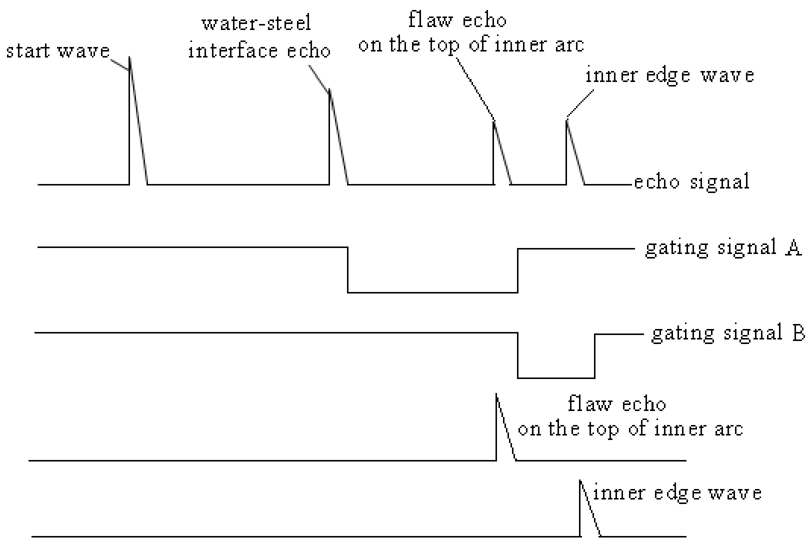

Fig. 9 Timing relation between echoes and gates

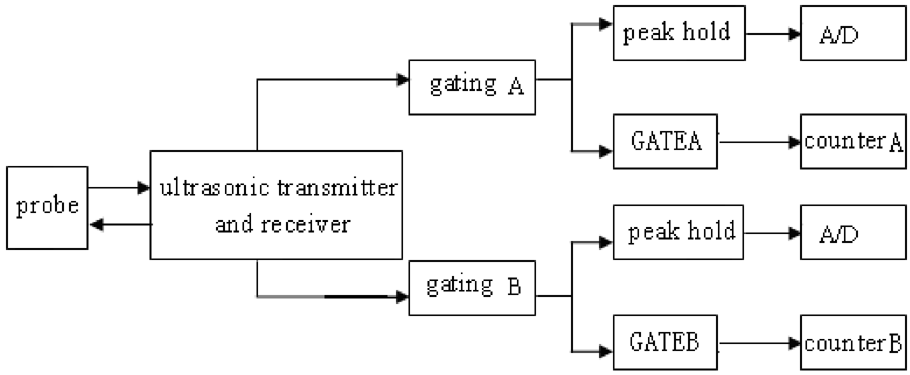

Fig. 10 Diagram of circuits

5 Detection System Architecture

In order to realize the continuous and on-line detection, the detection mode of rotating component and probe line marching is adopted. Working parameters of the system: rotate speed of workpiece is 480rad/min, line marching speed of the probe is 16mm/s, sampling frequency is 2 kHz. Fig.11 gives the block diagram of detection system.

The detection frock need complete tasks like automatic charging, rotating component, probe box marching, blanking and automatic sorting etc. PLC system gets the industrial computer command to control the process of detection frock. RS485 realizes the mutual communication of industrial computer with PLC. 8-chanel ultrasonic real-time

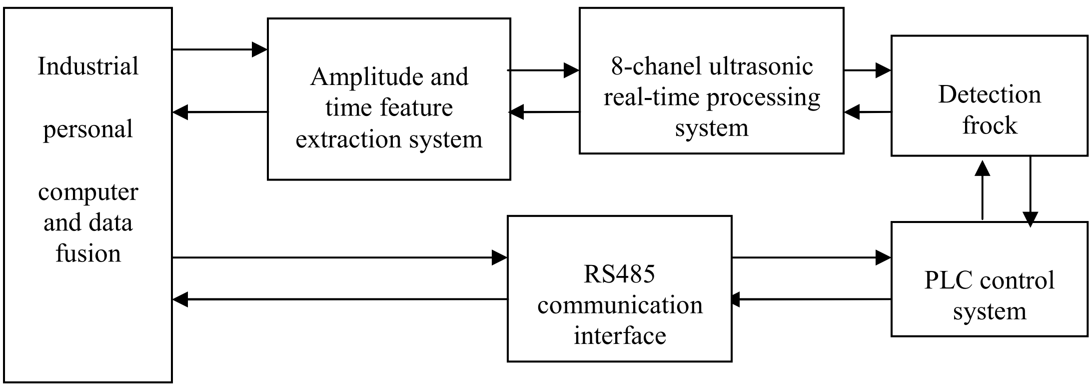

Fig.11 the block diagram of detection system

processing system takes charge of the generation, amplification, filtering and gate selection of ultrasonic signal. The amplitude and time feature extraction system completes the functions including sequential control, acquisition of high-speed signal, counting of time signal and transmitting time and amplitude to computer through ISA bus.

The main control computer has responsibility of setting working parameters, signal processing, data fusion defect recognition, detection results display and system working order coordination. The system workflow is shown in Fig.12.

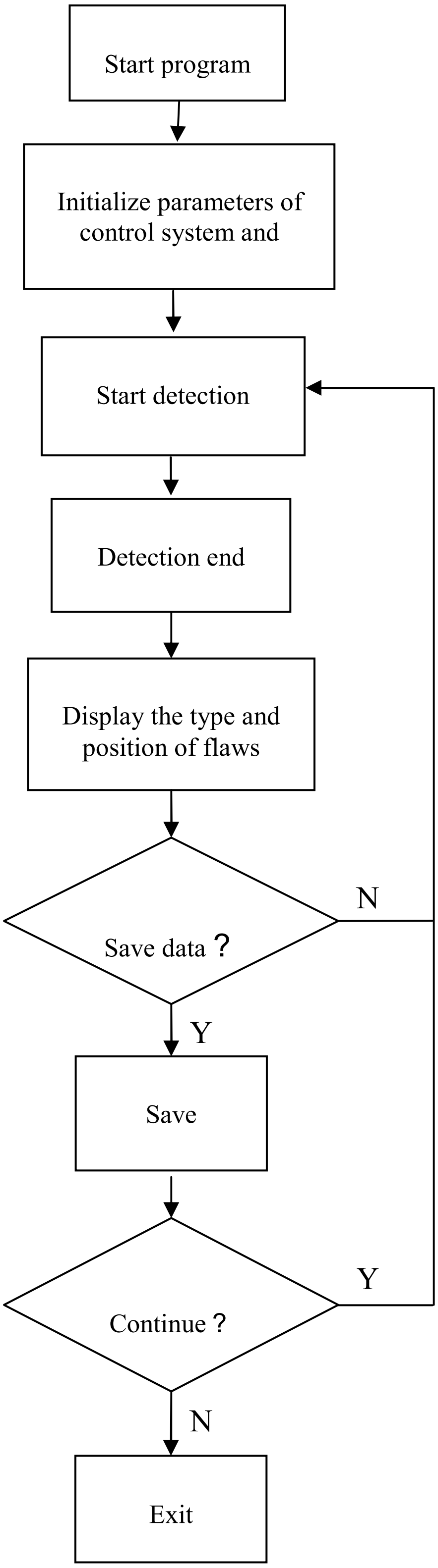

Fig. 12 The system workflow

6 Dynamic Flaw Characteristics and Processing Methods

Dynamic detection for component is made. The echo signal of 10mm length of transverse flaw is shown in Fig.13.

The processing methods of dynamic data are as follows:

(1) Meaning filter: There are unavoidably various kinds of noises during automatic detection. The rotation of motor, glossiness of detected component and the water flow speed etc, all of them will cause noise. So 5-point meaning filtering can be made for sampling data. Meaning filter can smoothing the sampling data and is helpful to latter processing.

(2) Two-value height filter: Firstly make two-value data processing on sampling data, that is set the corresponding threshold in the program. Compare sampling data with the threshold, put the data bigger than threshold as 1, and put the smaller as 0.

(3) Width filter: There exist slight shaking and surface stains in the automatic ultrasonic testing process. So all "1" value signal can not be considered as flaw. Effective way is to record the number of value bigger than the height threshold, and gate width value should be set in the program. If the number of record "1" is greater than gate width value, it is regarded as flaw. The smaller is considered as interference wave. From these two methods, it can be seen that the choice of the gate height value and gate width value is very important. If gate height value is too low and gate width value is too narrow, Erroneous judge will occur, otherwise undetected error will occur. So setting an appropriate gate is needed and it can be got through multiple detection of detected component.

7 Data Fusion

Data fusion is a technology of making synthesis and judgment on information got from many sensors according to certain regulation. The judgment is more accurate and reliable due to the sufficient information. The structure of multi-sensor fusion is divided into serial fusion, parallel fusion and mixing fusion. Parallel fusion processes and fuses information of various sensors in parallel, so it has faster processing speed and better efficiency. According to fusion level, data fusion is generally divided into data level fusion , feature level fusion and decision level fusion. Original data sampled are fused directly in data level fusion. The method has low efficiency due to a mass of data, but it can provide fine information that other method can not provide. In feature level fusion, feature extraction is made in advance from information got by sensors, and then comprehensive analysis and process are made on feature information. Decision level fusion is the highest level fusion. It fuses the local decisions of sensors, the fusion result is judgment basis. The efficiency of decision level fusion is the highest because local decision information of sensors can be processed in parallel[16-22].

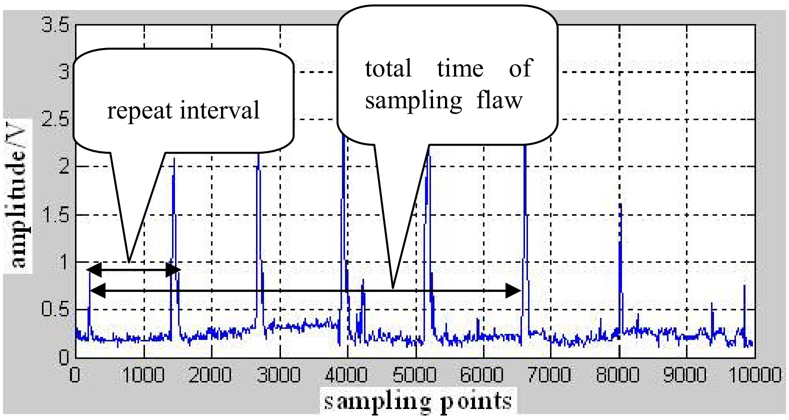

Fig.13 The echo signal of transverse flaw

The profiled component has complex structure of more angular and reflex end faces, strong interference signals such as inner edge wave exist. If only one probe data is used in flaw recognition, misjudgment is easy to make. Considering the requirement for the detection speed and detection efficiency in the meantime, the method is adopted in which firstly thickness, circumferential and axial probes are used in flaw recognition respectively and then the detect results of three probes are synthesized in decision-making and information fusion. Comprehensive evaluation is according to Table 1.

Because different type of flaw has different sensitivity to the position, type and attitude of the ultrasonic probe, so the data of one probe only describe certain aspect of detected component and only provide partial and limited information.

In order to make comprehensive assessment of the defects, multi-sensor data fusion with multiple variables is made from information of the circumferential and axial probes to determine the type of defects such as cracks, bubbles, inclusions and characteristics such as the size and shape of defects. The defect is located according to scanning points of the probe and moving screw pitch of the component. Firstly characteristics of period, duration and amplitude are extracted from the data of each probe feature extraction defect echo, and then comprehensive analysis and processing are made on information of the circumferential and axial probes. For example, when characteristic value of the defect signal meets Table 2, the type of defect can be judged as axial crack. When characteristic value of the defect signal meets Table 3, the type of defect can be judged as small bubble.

8 Conclusion

According to the structure of profiled component and distribution characteristic of flaws, ultrasonic testing method of profiled component is studied in this paper. Experimental results indicate that creep wave excited by ultrasonic immersion method with focus probe can ensure higher sensitivity and resolution of echo flaw signals. In order to eliminate impact of inner edge wave, the echo signal is divided into two parts to assure the fatal defect is not undetected, and further in order to improve the recognition accuracy of one probe, two characteristic values of time and amplitude of echo signal are extracted to distinguish between flaw signal and inner edge wave. Fusing data of thickness, circumferential and axial probes, comprehensive analysis and decision are made to improve the recognition accuracy and detection efficiency. the features of period, duration and amplitude of echo signals are extracted to improve the recognition accuracy of flaw type and overcome the limitation of one probe. The study on ultrasonic creep wave detection method and data fusion in this paper provides reference for automatic detection system of profiled component, in the meantime the method in this paper can be also applied to detect the other small diameter and thin-wall component.

Table1 Data fusion of qualitative flaw recognition

Circumferential probe	√		√			√
Axial probe	√	√			√	√
Thickness probe			√	√	√	√
Defectiveness	√		√		√	√

Pay attention: √ means defectiveness

Table2 Features of axial crack

	Period		Duration		Amplitude	
	big	small	big	small	big	small
Circumferential probe	√			√		√
Axial probe		√		√		√

Table3 Features of small bubble

	Period		Duration		Amplitude	
	big	small	big	small	big	small
Circumferential probe		√		√	√	
Axial probe		√		√	√	

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