The Method of Adjusting Ultrasonic Testing Sensitivity by Calculation for Intermediate Blank of TC17 Alloy Forging

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Abstract: For the ultrasonic detection of the intermediate blank of TC17 alloy forging, the problem of high clutter level exists when the sensitivity is adjusted by the bottom wave calculation method. Taking GH4169 and TC17 in which the scattering attenuation in ultrasonic testing is different as samples, the attenuation coefficient measurement experiment and the sensitivity adjustment experiment by calculation method were carried out to explore the influence of scattering attenuation on the sensitivity adjustment by calculation method for ultrasonic detection. On this basis, a method of sensitivity adjustment by zoning calculation for TC17 intermediate blank was proposed and compared with the first-order bottom-wave method. The result shows that the method of sensitivity adjustment by zoning calculation is far superior to the first-order bottom-wave method in clutter. The problem of the ultrasonic testing of TC17 intermediate blank is solved effectively.

Keywords: TC17 intermediate blank; Ultrasonic testing; Calculation method; Sensitivity; Clutter

1 Introduction

The vane-integrated disk of an aero-engine are manufactured with TC17 alloy forgings. The ultrasonic testing of the intermediate blank must be carried out reliably and accurately to ensure the quality of the intermediate blank, because the quality of forgings is greatly influenced by the intermediate blank. The thickness of the intermediate blank is usually above 200mm, and the sensitivity is adjusted by calculating method. The calculation method[1] is the means to adjust the gain of altrasonic testing instruments. It is based on the theoretical difference between the wave height of the artificial defect (usually the flat bottom hole) and the reflected wave height of a reflector. In practice, the echo of the reflector is adjusted to the specified screen height first, and then the gain of the instrument is adjusted according to the calculated difference.TC17 alloy has higher scattering attenuation than other alloys[2, 3]. When the

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sensitivity of the intermediate blank ultrasonic testing is adjusted directly by the bottom wave calculation method, the clutter level is high and the signal-to-noise ratio is low, which greatly affects the reliability and accuracy of the detection.

In this paper, the influence of scattering attenuation on the sensitivity of ultrasonic detection was studied. Taking GH4169 and TC17 in which the scattering attenuation in ultrasonic testing is different as samples, the attenuation coefficient measurement experiment and the sensitivity adjustment experiment by calculation method were carried out. A method for adjusting the detection sensitivity of TC17 intermediate blankt is proposed to realize the reliable and accurate ultrasonic testing of TC17 intermediate blank.

2 The principle of adjusting sensitivity by traditional bottom wave calculation method

For the samples with the surface parallel up and down and the bottom surface is relatively flat and the thickness x≥3N (near-field region length).The detection sensitivity can be adjusted by the method of bottom wave calculation.

According to the large flat bottom echo pressure formula and the flat bottom hole echo pressure formula, the acoustic pressure decibel difference between the large flat bottom and the flat bottom hole that the diameter is d at the same depth can be obtained as follows:

$$\Delta\mathrm{dB} = 20\lg\frac{P}{P_D} = 20\lg\frac{\pi d^2}{2\lambda x} = 20\lg\frac{\pi f d^2}{2cx} \qquad (1)$$

In the equation, P is the echo pressure of the flat bottom hole required by the sensitivity, P_D is the sound pressure of the large flat bottom, f is the ultrasonic frequency, d is the diameter of the flat bottom hole required by the detection sensitivity, c is the sound velocity in the material.

When the sensitivity is adjusted by the method of bottom wave calculation, the echo amplitude of the bottom surface of the workpiece is usually adjusted to 80% of the instrument screen, then add the calculated value according to the given acceptance flat bottom hole diameter. At present, the detection sensitivity can ensure that the reflected echo amplitude of the flat bottom hole at the same sound path as the thickness of the workpiece is up to 80% of the screen.

3 Measurement principle of propagation attenuation coefficient of ultrasonic

When ultrasonic wave propagates through material, the phenomenon that the sound pressure or sound energy decreases gradually with the increase of distance is called the propagation attenuation of ultrasonic wave[4]. There are three reasons for attenuation[5]: (1) the diffusion of sound beams (diffusion attenuation); (2) the scattering of sound waves by grains or other tiny particles in the material (scattering attenuation); (3) the absorption of medium (absorption attenuation).

In practical ultrasonic testing, the propagation attenuation of ultrasonic wave in medium usually refers to scattering attenuation and absorption attenuation. For coarse-grained materials, scattering attenuation is the most important factor affecting the detection[6-8]. The scattered ultrasound travels along complex paths in the medium, some of which may become thermal energy, and the other of which may eventually propagate to the probe, forming a grass-shaped echo (or noise) of the screen in the process of detection. On the one hand, the attenuation of acoustic energy results in the decrease of echo signal, on the other hand, the increase of scattering noise makes the signal-to-noise ratio of detection seriously decrease.

In order to characterize the propagation attenuation coefficients of different scattering attenuation materials, the attenuation coefficient α can be measured by the number of decibels of sound pressure attenuation after ultrasonic wave passing through a certain thickness of the material. Dividing the attenuation amount (ΔdB) by the thickness is the attenuation coefficient α. When measuring the attenuation coefficient, the surface and bottom of the specimen should be parallel, and their roughness should be the same. When measuring, the straight probe is placed on the surface of the specimen, so that the sound wave is reflected repeatedly in the specimen, and there are many bottom waves on the display screen. Due to propagation attenuation and reflection loss, the bottom wave height decreases sequentially, as shown in figure 1. The attenuation coefficient of the medium can be calculated according to formula (2):

$$\alpha = \frac{20\lg\frac{\mathrm{H_m}}{\mathrm{H_n}} - 20\lg\frac{\mathrm{n}}{\mathrm{m}} - (\mathrm{n}-\mathrm{m})\delta}{2(\mathrm{n}-\mathrm{m})x} \qquad (2)$$

In the equation, Hm and Hn is the height of m and n bottom wave, m and n is the m and n bottom wave, n > m, δ is the reflection loss of the bottom, and the reflection loss of each bottom is about (0.5 ~ 1) dB, x is the thickness of the specimen.

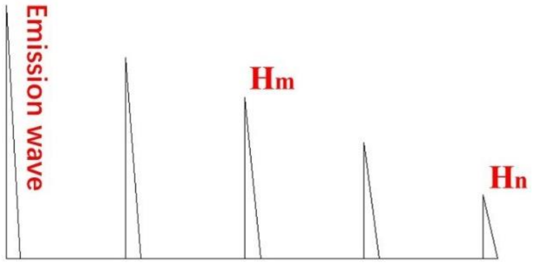


Fig. 1. Attenuation coefficient measuring principle diagram

When measuring attenuation coefficient by formula (2), the selected m value should meet the requirement of mx ⩾ 3N, on the other hand, the roughness of surface and bottom of the workpiece should be small enough, usually up to Ra 1.6 μ m, and there should be no water, oil and other debris on the bottom during the measurement.

4 The effect of scattering attenuation on the adjustment of ultrasonic testing sensitivity by calculation method

4.1 Development of contrast sample of different scattering attenuation materials

According to the principle of adjusting ultrasonic testing sensitivity by calculation method and the design requirement of damage tolerance of the intermediate blank(defects of Φ1.2 flat bottom hole equivalent can be detected), TC17 and GH4169 forgings were selected to make two sets of contrast samples. Each group of samples consist of a large flat bottom test block and a flat bottom hole test block, as shown in figure 2. In order to ensure that the acoustic characteristics of the large flat bottom test block and the flat bottom hole test block are similar, the material was taken from the same part of the forging structure as possible, and the material object is developed as shown in fig. 3.

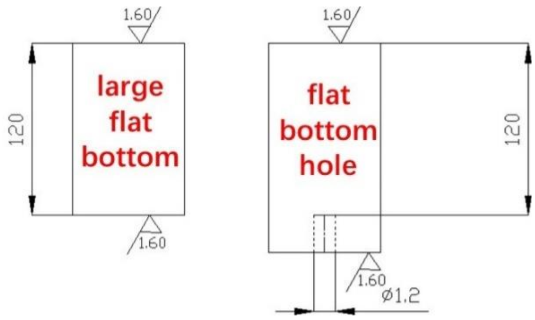


Fig. 2. The design of contrast samples

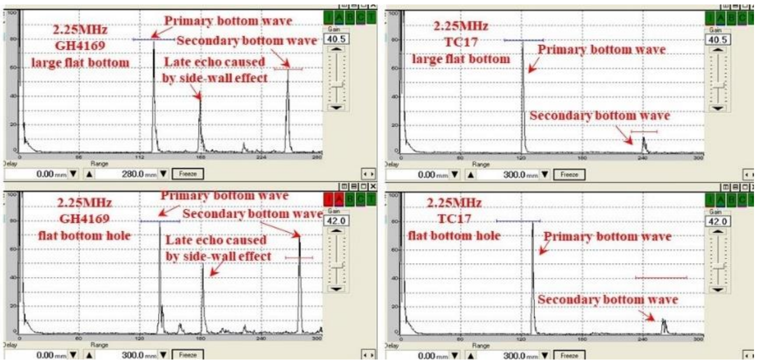
Fig. 3. The material object of contrast samples

4.2 Measurement of attenuation coefficient of contrast samples

Two probes with frequencies of 5MHz and 2.25MHz were selected to measure the attenuation coefficient of the large flat bottom test block and the flat bottom hole test block in TC17 and GH4169 samples. The test probe is shown in figure 4, and the ultrasonic testing instrument was USIP40.

Fig. 4. The test probes

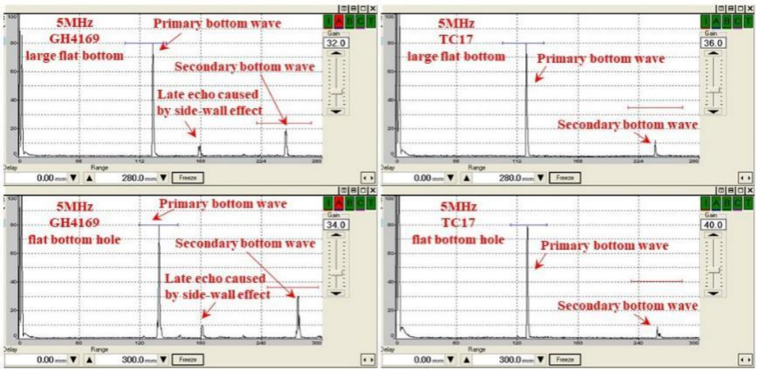
When the frequency is 2.25MHz, the attenuation measurement results of the GH4169 large flat bottom test block and the flat bottom hole test block are shown in fig. 5 (a). Because of the obvious side-wall effect caused by the diffusion of sound beam, the actual measurement results will be influenced by the side-wall effect, which will result in errors. From the medium attenuation coefficient formula (2), $\alpha_{2.25\text{-}4169\text{-}LFB}$=0.0166dB/mm, $\alpha_{2.25\text{-}4169\text{-}FBH}$=0.0199dB/mm. The attenuation measurement results of the TC17 large flat bottom test block and the flat bottom hole test block are shown in fig. 5 (b). It can be concluded that, $\alpha_{2.25\text{-}17\text{-}LFB}$=0.0415dB/mm, $\alpha_{2.25\text{-}17\text{-}FBH}$=0.0383dB/mm.



（a） GH4169　　（b）TC17

Fig. 5. Frequency 2.25MHz, attenuation coefficient measurement waveform

When the frequency is 5MHz, the attenuation measurement results of the GH4169 large flat bottom test block and the flat bottom hole test block are shown in fig. 6 (a). The side-wall effect decreases significantly. From the medium attenuation coefficient formula (2), $\alpha_{5\text{-}4169\text{-}LFB}$=0.023dB/mm, $\alpha_{5\text{-}4169\text{-}FBH}$=0.0074dB/mm. The attenuation measurement results of the TC17 large flat bottom test block and the flat bottom hole test block are shown in fig. 6 (b). It can be concluded that, $\alpha_{5\text{-}17\text{-}LFB}$=0.0415dB/mm, $\alpha_{5\text{-}17\text{-}FBH}$=0.0479dB/mm.



（a） GH4169 （b）TC17

Fig. 6. Frequency 5MHz, attenuation coefficient measurement waveform

4.3 Adjustment sensitivity test of contrast samples by calculation method

The adjustment sensitivity test of large flat bottom test block and bottom hole test block in TC17 and GH4169 samples was carried out with the probes which are used in the attenuation coefficient measurement test.

The longitudinal wave sound velocity in GH4169 is 5820m/s, the longitudinal wave sound velocity in TC17 is 6180m/s. The test instrument was USIP40, and the parameter setting of the instrument was the same as the test of attenuation coefficient measurement.

The attenuation of the samples measured at different frequencies is shown in Table 1.

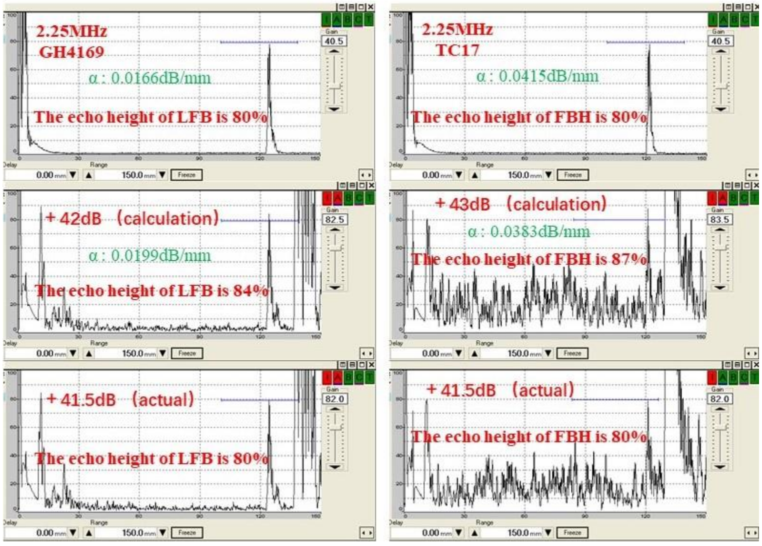
Table 1. The attenuation of the contrast samples

Frequency	GH4169 LFB	GH4169 FBH	TC17 LFB	TC17 FBH
2.25MHz	0.0166dB/mm	0.0199dB/mm	0.0415dB/mm	0.0383dB/mm
5MHz	0.023dB/mm	0.0074dB/mm	0.0415dB/mm	0.0479dB/mm

When the frequency is 2.25MHz, it can be obtained from the adjustment sensitivity by calculation method formula (1) that: $\Delta dB_{2.25\text{-}4169}=42dB$，$\Delta dB_{2.25\text{-}17}=43dB$.

The result of adjustment sensitivity of the GH4169 samples by calculation method is shown in figure 7 (a). The echo height of the flat bottom hole (Φ1.2) was 84% after adjusting the sensitivity by calculation method, it is greater than 80%. It indicates that the scattering attenuation of the GH4169 flat bottom hole test block should be less than that of the GH4169 large flat bottom test block. However, the scattering attenuation of the flat bottom hole test block measured in practice is slightly higher than that of the large flat bottom test block. This is due to the side-wall effect.

The result of adjustment sensitivity of the TC17 samples by calculation method is shown in figure 7 (b). The echo height of the flat bottom hole (Φ1.2) was 87% after adjusting the sensitivity by calculation method, it is greater than 80%. It indicates that the scattering attenuation of the GH4169 flat bottom hole test block should be less than that of the GH4169 large flat bottom test block, it consists with the actual measurement result. When the echo height of GH4169 LFB and TC17 LFB is up to 80%, the gain of the instrument is the same. This is due to the attenuation caused by the side-wall effect in the large flat bottom test block of GH4169.



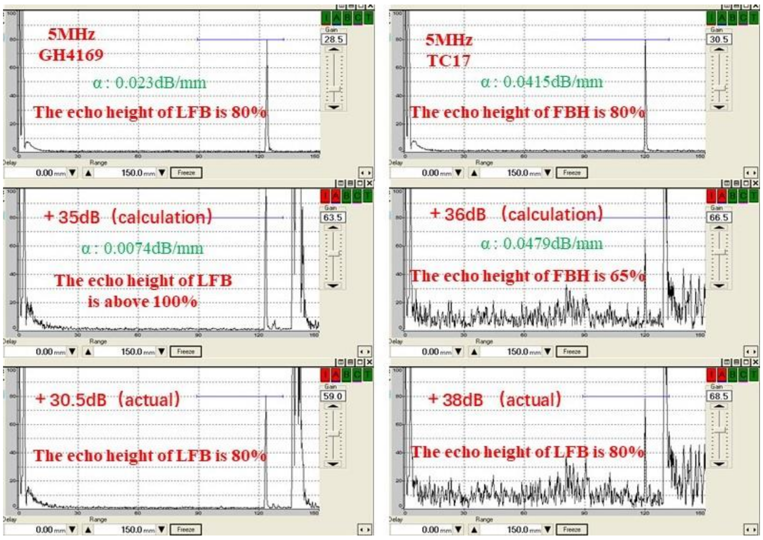
（a） GH4169 （b）TC17

Fig. 7. Frequency 2.25MHz, sensitivity adjustment by calculation waveform

When the frequency is 5MHz, it can be obtained from the adjustment sensitivity by calculation method formula (1) that: $\Delta dB_{5\text{-}4169}=35dB$，$\Delta dB_{5\text{-}17}=36dB$.

The result of adjustment sensitivity of the GH4169 samples by calculation method is shown in figure 8 (a). The echo height of the flat bottom hole (Φ1.2) was above 100% after adjusting the sensitivity by calculation method, it is greater than 80%. It indicates that the scattering attenuation of the GH4169 flat bottom hole test block should be less than that of the GH4169 large flat bottom test block, it consists with the actual measurement result.

The result of adjustment sensitivity of the TC17 samples by calculation method is shown in figure 8 (b). The echo height of the flat bottom hole (Φ1.2) was 65% after adjusting the sensitivity by calculation method, it is less than 80%. It indicates that the scattering attenuation of the TC17 flat bottom hole test block should be less than that of the TC17 large flat bottom test block, it consists with the actual measurement result.



（a） GH4169 （b）TC17

Fig.8. Frequency 5MHz, sensitivity adjustment by calculation waveform

4.4 Nodulus

By measurement of attenuation coefficient of contrast samples and adjustment sensitivity test of contrast samples by calculation method, it can be concluded that:

1. The adjustment sensitivity by calculation method is not affected by scattering attenuation, and scattering attenuation will only lead to the increase of the clutter.
2. The clutter level of TC17 samples is much higher than that of GH4169 samples.
3. When detecting the TC17 samples with the 5MHz probe, the sensitivity is higher than detecting the TC17 samples with the 2.25MHz probe, and the clutter is lower than detecting the TC17 samples with the 2.25MHz probe.
4. When detecting the samples with the 2.25MHz probe, the scattering attenuation of TC17 large flat bottom test block is greater than that of TC17 flat bottom hole test block. However, when detecting the samples with the 5MHz probe, the scattering attenuation of TC17 large flat bottom test block is less than that of TC17 flat bottom hole test block. This shows that the scattering attenuation depends on the interaction between the grain or the interaction between tiny particles in the material and the ultrasonic beam. and the ultrasonic beam produced by different ultrasonic frequency and wafer size will lead to the difference of scattering attenuation. Different ultrasonic beams produced by different frequency and the wafer size will lead to the difference of scattering attenuation.

5 Optimization of adjustment sensitivity method for detecting the intermediate blank

The adjustment sensitivity by calculation method is not affected by scattering attenuation, and scattering attenuation will only lead to the increase of the clutter. Based on this, a partition calculation method is proposed to adjust the detection sensitivity. The details are as follows.

Let the thickness of the intermediate blank be x, (x/2)>3N=99mm, since the thickness of the intermediate blankt of TC17 alloy forgings is usually above 200mm. If the zone is divided by half of the thinkness of the intermediate blank (x/2), then there is a difference of 6 dB between the large flat bottom at (x/2) and the large flat bottom at x. When the height of bottom wave at x is 40%, the height of bottom wave at (x/2) is 80%. When detecting, the height of the bottom wave is adjusted to 40%, the height of the hypothetical bottom wave at half of the workpiece is 80% right now, then plus ΔdB calculated at half of the workpiece to complete the inspection of the half workpiece. Repeat the inspection from another end of the workpiece to complete the inspection of the other half workpiece.

Compared with the primary bottom wave method, the clutter signal can be significantly reduced by subaera detecting. Taking the Φ1.2mm flat bottom hole as the detection sensitivity, the above-mentioned detection method was verified by TC17 large flat bottom contrast samples which height is 120mm at frequency 2.25MHz and 5MHz. The sensitivity values at different frequencies and thicknesses are shown in Table 2. The results are shown in Fig. 9 and Fig. 10. It can be seen that the clutter signal is obviously reduced after partition.

Table 2. The sensitivity values at different frequencies and thicknesses

Frequency	ΔdB（x/2）	ΔdB（x）
2.25MHz	37dB	43dB
5MHz	30dB	36dB

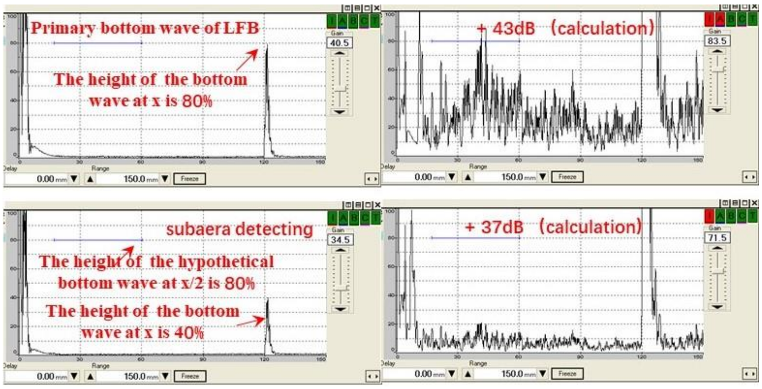


Fig.9. Frequency 2.25MHz, comparison of Clutter between Subarea calculation method and primary bottom wave calculation method

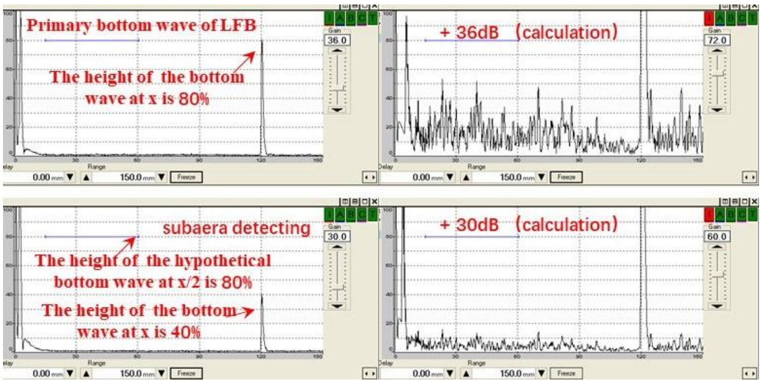


Fig.10. Frequency 5MHz, comparison of Clutter between Subarea calculation method and primary bottom wave calculation method

6 Conclusions

(1) The adjustment sensitivity by calculation method is not affected by scattering attenuation, and scattering attenuation will only lead to the increase of the clutter.

(2) The method of adjusting detection sensitivity by subarea calculation can solve the problem of high clutter and low signal-to-noise ratio in TC17 intermediate blanks ultrasonic testing using the conventional primary bottom wave calculation method to adjust the detection sensitivity.

(3) The results show that the method proposed in this paper is suitable for adjusting the detection sensitivity of TC17 intermediate blank, and the ultrasonic testing of TC17 intermediate blank is realized reliably and accurately.

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