Analysis on Main Influence Factors for Ultrasonic Flaw Detection of Steel Weld

Tao Du¹, Jiandong Sun¹, Dong Liu ², Yujun Guo³, Qing Gao⁴
¹Shandong Academy of Building Research Institute of Structure Jinan; 250031
²Feicheng Construction Engineering Quality Supervision Station Tai'an; 271000
³Shandong Provincial Department of housing and urban rural development Jinan; 250000
⁴Shandong Hi-speed Company Limited Jinan; 250000

dt7777@126.com

Abstract. The paper determined several main factors influencing ultrasonic detection results through research and analysis on the influence results and accuracy during the ultrasonic flaw detection of steel structure weld, and made a summary how to select and operate instruments correctly, utilize favorable factors of detection results and avoid unfavorable factors, as well as improve detection accuracy during the practical detection.

1. Overview
The implementation of new Code for Construction Quality Acceptance of Steel Structure Work GB50205-2001 strengthens the site inspection of steel structure, especially the approaches adopted by site random inspection, which properly ensures safety and durability of steel structure work. Quality inspection of welds is vital to quality control of steel structure work. The new acceptance code puts more emphasis on the ultrasonic flaw detection of steel weld, and the research of this part plays an important role as well in our subject "analysis on NDT technology of steel structure". When an ultrasonic unit is used, the defect position and size are mainly determined by the position and height of defect echo on the fluorescent screen. The position and the height of the factors influencing the echo appear are manifold, we summarized several main factors affecting the accuracy of ultrasonic detection results from many years of practical experience and subject research in engineering detection (excluding the human-made factor), and it is quite important to learn about these factor for correctly selecting instruments and accessories and detection methods, making full use of favorable factors and avoiding unfavorable factors in ultrasonic detection results, and enhancing the accuracy of detection results.
2. **Selection and Use of Detector**

Union Pxut-3300 six channels full digital ultrasonic detector is selected. It is equipped with a 0.8Kg battery, and the light weight, high luminance and long continuous working hours are suitable for site detection. In particular, its performance indexes represent the highest level of current ultrasonic detection of steel structure.

3. **Several Main Influence Factors**

3.1 **Influence of couplant materials (acoustic impedance)**

To improve the detection results, a layer of acoustically transparent media between probe and workpiece surface, i.e. couplant. The couplant is used to exhaust air between probe and workpiece surface and further to effectively transmit the ultrasonic wave into workpiece. Ultrasonic coupling refers to sound intensity transmissivity of ultrasonic wave on the detection surface. Better ultrasonic coupling effect causes higher sound intensity transmissivity with high echo amplitude, which is easy for analyzing defects. Couplant should meet the following requirements:

1. Be able to wet workpiece and probe surface, with proper fluidity, viscosity and adhesion, easy to be cleaned;
2. With high acoustic impedance and good sound transparent property;
3. With wide source, low cost, no corrosion to workpiece and no harmful to human body;
4. Stable property, not easy to go bad, long storage life.

Engine oil, water and chemical paste are selected to be the study objects based on the above requirements considering the above detection practices.

Acoustic impedance Z is the ratio between sound pressure P at a certain point and particle vibration velocity V at this point, i.e. \( Z = \frac{P}{V} = \rho c \) (where, \( \rho \) is media density, c is ultrasonic velocity in media).

The acoustic impedances of the above three couplants are determined as follows by reference to related material standards: (See Table 1)

| Media                      | Z (kg/m².s) |
|---------------------------|-------------|
| Engine oil                | 1.28        |
| Water                     | 1.50        |
| Carboxymethyl cellulose adhesive | 2.20    |

The influence degree of coupling material on defected wave height is tested, and the experiment is carried out on CSK-III A standard test block. The horizontal holes with depth of 10mm, 20mm, 30mm and 40mm are taken as standard defects to test its maximum wave height. The data obtained is shown as follows:

Engine oil as couplant: (See Table 2)

| Cover depth of holes (mm) | Maximum wave height of attenuation values (mm) |
|---------------------------|-----------------------------------------------|
| 10                        | 50  |
| 20                        | 46  |
| 30                        | 42  |
| 40                        | 37  |
(dB) | 45 | 48 | 41 | 37  
---|----|----|----|----
     | 49 | 45 | 41 | 37  
Average value (m) | 49 | 45 | 41 | 37  

Notes: The attenuation value which reduces the maximum echo height to 80% of full screen is taken as a comparative value.

Water as couplant: (See Table 3)

| Maximum wave height of attenuation values (dB) | Cover depth of holes (mm) |
|-----------------------------------------------|---------------------------|
| 10                                            | 20 | 30 | 40  |
| 50                                            | 46 | 41 | 38  |
| 50                                            | 46 | 41 | 37  |
| 49                                            | 46 | 41 | 37  |
| Average value (m)                             | 50 | 46 | 41 | 37  |

(3) Chemical paste as couplant: (See Table 4)

| Maximum wave height of attenuation values (dB) | Cover depth of holes (mm) |
|-----------------------------------------------|---------------------------|
| 10                                            | 20 | 30 | 40  |
| 51                                            | 47 | 41 | 38  |
| 51                                            | 47 | 42 | 39  |
| 51                                            | 46 | 42 | 39  |
| Average value (m)                             | 51 | 47 | 42 | 39  |

See Figure 1 for curve graph.

![Figure 1](image_url)

**Figure 1.** The curves from top to bottom represent chemical paste, water and engine oil, respectively.

It can be observed from the standard defect and wave height that the average height of water as couplant is about 0.5dB higher than engine oil as couplant. The reading of digital ultrasonic amplitude attenuator is generally accurate to 1dB, and that of analog type ultrasonic amplitude attenuator is accurate to 2dB. The influence of water and engine oil on defect amplitude can be ignored. On the other hand, the average
The echo height of chemical paste is 2dB higher than engine oil as couplant, which shows that the acoustical coupling effect of chemical paste is the best. However, if the steel workpiece surface is not processed timely, water and chemical paste (its main component is water) will cause corrosion. In contrast, engine oil is featured with proper viscosity, fluidity and cohesion, and the practical test shows that the engine oil can effectively reduce the friction between probe and the workpiece surface to be tested for more convenient detection. To sum up, the engine oil is recommended to be adopted as couplant.

3.2 Influence on external force applied to test probe

It can be deferred from detection experience that when ultrasonic detection is carried out by manual with the same couplant, the larger the external force applied to the probe, the higher the defect reflection echo obtained is. The experiment is carried out on an electronic scale, and the horizontal holes with depth of 10mm, 20mm, 30mm and 40mm are also taken as standard defects to test its maximum wave height. The data is obtained as Table 5.

| Classification | Cover depth of holes (mm) |
|----------------|---------------------------|
| ①              | 10 | 20 | 30 | 40 |
| ②              | 46 | 41 | 37 | 34 |
| ③              | 49 | 45 | 40 | 37 |
| ④              | 50 | 46 | 42 | 38 |
| ⑤              | 51 | 46 | 42 | 39 |

Notes: The ①②③④⑤ in the above table are the comparative values to the average attenuation values when the maximum wave height is reduced to 80% of the full screen under the external forces of 0.1kgf, 0.25kgf, 0.5kgf, 0.75kgf and 1kgf.

See Figure 2 for curve graph.

![Figure 2](image_url)

**Figure 2.** The external forces from top to bottom are 1kgf, 0.75kgf, 0.5kgf, 0.25kgf and 0.1kgf.

It can be seen that 0.5kgf is the demarcation point of external forces applied to the test probe. When the external force is less than 0.5kgf, the reflection wave height drops fast, and when it is larger than 0.5kgf, the reflection wave height increases slowly, which can be ignored considering the detector attenuation accuracy of 1dB or 2dB.
Therefore, it is suggested that the detection personnel should apply even force of approximately 0.5kgf on the probe during the practical detection.

3.3 Influence of workpiece surface roughness
The practical detection proves that the roughness of workpiece surface has a significant influence on acoustical coupling. Two blocks of steel plate in size of 300mm×300mm×10 mm were selected to be jointed by fusion-through welding. Simulate a cavity defect at the weld, use the probe to detect at the same side, position and direction, and then quantify the defects. The roughness of steel plate surface was handled by four methods: surface non-treatment, sanding (surface finishing), oxidized surface layer polishing by steel brush and mechanical polishing, as shown in Figure 3:

![Figure 3. Detection of schematic diagram.](image)

Attenuation reading of defect wave height: (See Table 6)

| Media / instrument reading (dB) | ① | ② | ③ | ④ |
|-------------------------------|----|----|----|----|
| Engine oil                    | 32 | 36 | 37 | 37 |
| Water                         | 34 | 37 | 37 | 38 |
| Carboxymethyl cellulose adhesive | 34 | 36 | 37 | 37 |

Notes:①②③④ represents the four surface treatment methods: namely surface non-treatment, sanding, oxidized surface layer polishing by steel brush and mechanical polishing.

The table infers that the higher surface roughness generally generates poorer coupling effect with lower reflection echo when the same couplant is used. With regard to the couplant with lower acoustic impedance, the higher surface roughness generally have greater influence on reflection amplitude. It also can be observed that after the workpiece surface is polished by abrasive paper, the reflection amplitude is seldom effected if further surface treatment is carried out to improve its degree of finish. Thus the workpiece surface is only required to be polished by manual to ensure there is no welding slag or other foreign matters and the probe can move smoothly on workpiece surface during the practical detection.

3.4 Influence of workpiece shape
Workpieces to be tested are not only flat and straight steel plate, but plates or pipes with different curvature radius to be connected by welding. The probe surface is flat when it is manufactured, so it may have point contact or line contact when contacting with a hook surface, which will cause a loss of effective acoustic energy. The incoming sound pressure of ultrasonic wave against reflector is in direct
proportion to the effective chip area. If the coupling area decreases, the incoming sound pressure will reduce accordingly, which will result in a reduction of reflection wave height and detection sensitivity. It certainly will affect the defect quantitative and leak detection. To increase the effective contact area between probe and surface to be tested, it is necessary to polish the curvature to be tested of the probe. The polished probe is shown in Figure 4:

![Image of polished probe in detection of workpiece with small curvature radius.]

Figure 4. Polished probe in detection of workpiece with small curvature radius.

The research on butt-welded seam of steel pipe with different curvature showed that the defect reflection echo is relatively stable when the curvature radius is larger than 20mm, and similar echo amplitude can be received at the same position in repeated detections. But the reflection echo is not stable when the curvature radius is less than 20mm, and reflection echo may not be received at the same position in repeated detections. The research results indicated that the defects is possible to be undetected when the curvature radius of a workpiece is less than 20mm. When the probe surface is polished to a similar status of workpiece curvature, the defect reflection echo will recover to stable. For the purpose of conservation, it is suggested that when the curvature radius of a workpiece is less than 40mm during the practical operation, the possibility of leak detection can be considerably decreased if the probe surface is polished to as similar status with workpiece curvature.

3.5 Influence of working temperature

We studied the influence of working temperature on ultrasonic detection results. The common wave conversion media such as water and chemical paste have a considerable change in sound velocity under different temperatures. For example, when the media is water, the sound velocity of ultrasonic wave under different temperatures: (See Table 7)

| Temperature t (℃) | 10  | 20  | 25  | 30  | 40  | 50  | 60  | 70  | 80  |
|-------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Sound velocity (m/s) | 1448 | 1483 | 1497 | 1510 | 1530 | 1544 | 1552 | 1555 | 1554 |

However, when the incidence angle of ultrasonic wave is slant, the reflection wave and the propagation direction of refracted wave are determined by reflection-refraction law (i.e. Snell's law). Namely:

\[
\sin \alpha \frac{CL_1}{\sin \alpha \frac{CL_1}{} = \sin \beta \frac{C_1}{\sin \beta \frac{C_1}{} = \sin \beta \frac{C_2}{\sin \beta \frac{C_2}{}}
\]

Wherein: \( \alpha \) ---incident angle of longitudinal wave

\( \alpha \) \( \alpha \)ls---reflex angle of longitudinal wave
α s----reflex angle of horizontal wave

β l----refraction angle of longitudinal wave

β s----refraction angle of horizontal wave

CL1----longitudinal wave velocity of the first media
Cs1----transverse wave velocity of the first media
C12----longitudinal wave velocity of the second media
Cs2----transverse wave velocity of the second media

The longitudinal wave detection of angle probe is taken as an example, i.e. :\( \sin \alpha l/CL1= \sin \beta l/C12 \), it is known that when the temperature changes, the incidence angle of probe remain unchanged, but the sound velocity of ultrasonic wave in the first media (water) and the second media (steel) change, which resulting in a change of \( \sin \beta l \), i.e. a change in refraction angle \( \tan \beta l \) (K value). In the experiment, a CSK-IA test block is put in water with a temperature of 60°C. Water is adopted as couplant (media) to test K value of 2.5PK2 angle probe. When the temperature of test block and water temperature reach 50°C after 5 minutes, K value of the probe is measured to be 2.32, but the K value is measured to be 1.95 when the probe is in an ambient temperature of 22°C. We can see that the K value reduces 0.57, which is significantly different from the nominal value (K=2.0).

In the practical detection, if the working temperature is not significantly different from the ambient temperature, measured K value under the ambient temperature can be used directly without modification. But when the working temperature is considerable different from the ambient temperature, a test must be conducted to the probe performance by simulating the working temperature to correct the detection results.

4. Conclusion

It is of great help for our practical operation to understand the above five factors influencing ultrasonic detection results. During the practical detection, the test accuracy can be improved by selecting correct instruments and operating methods, making the most of favorable detection results and avoiding the unfavorable ones.

References

[1] National Standard of the People's Republic of China, “Code for Construction Quality Acceptance of Steel Structure Work GB50205-2001”, Beijing, China Pressing Press, 2001

[2] National Standard of the People's Republic of China, “Classification for Manual Ultrasonic Flaw Detection Methods and Results of Steel Weld GB/T11345-89”, Beijing, 1990

[3] Ultrasonic Flaw Detection Group "Ultrasonic Flaw Detection", Labor and Personnel Press, 1989

[4] Japan Nondestructive Inspection Association, Ma Yukuan et al ., “Translation of Ultrasonic inspection”, Jilin Science and Technology Press, 1984
[5] Hu Tianming “Ultrasonic Flaw Detection”, Wuhan University of Science and Technology of Surveying and Mapping Press, 1994
[6] Ultrasonic Flaw Detection Group "Ultrasonic Flaw Detection", Electric Power Industry Press Press, 1980
[7] Yun Qinghua et al., “Nondestructive Testing”, Labor Press, 1983
[8] Yun Qinghua, "Nondestructive Testing Technology for Boiler Pressure Vessel", Tianjin science and Technology Press, 1985
[9] Jiang Weiping, “Ultrasonic Testing”, Wuhan University of Surveying and Mapping Press, 1991
[10] Zhang Junzhe et al. “Nondestructive Testing Technology and Its Application”, Science Press, 1993
[11] Nondestructive Testing Society of Japan, Ma Ming et al., "Ultrasonic Flaw Detection A", Jiangsu Science and Technology Press, 1982