17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China

Studies of Broad-band Ultrasonic Techniques for Inspection of Bounding Quality in ITER First Wall

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Abstract

International Thermonuclear Experimental Reactor (ITER) is a big international cooperative project. China is in charge of first wall (FW) research which is made of blanker Be, Copper alloy and SS cooling tubes. The inspection of bonding quality between Be-Cu-SS tubes is essentially necessary. According to the structure and material acoustic characteristics, the acoustic amplitude-phase was theoretically analyzed, and a broad-band ultrasonic scanning system and a rotated acoustic mirror device were developed. The experimental results indicate that the broad-band ultrasonic technique is one of the most effective methods to evaluate bounding quality in ITER.

Key Words: ITER, First Wall, bonding quality Examination, Broad－band Ultrasonic，acoustic mirror

1. Introduction

International Thermonuclear Experimental Reactor (ITER) is one of the biggest international co-operation projects. China will carry out the tasks of R&D of the ITER Blanket System.

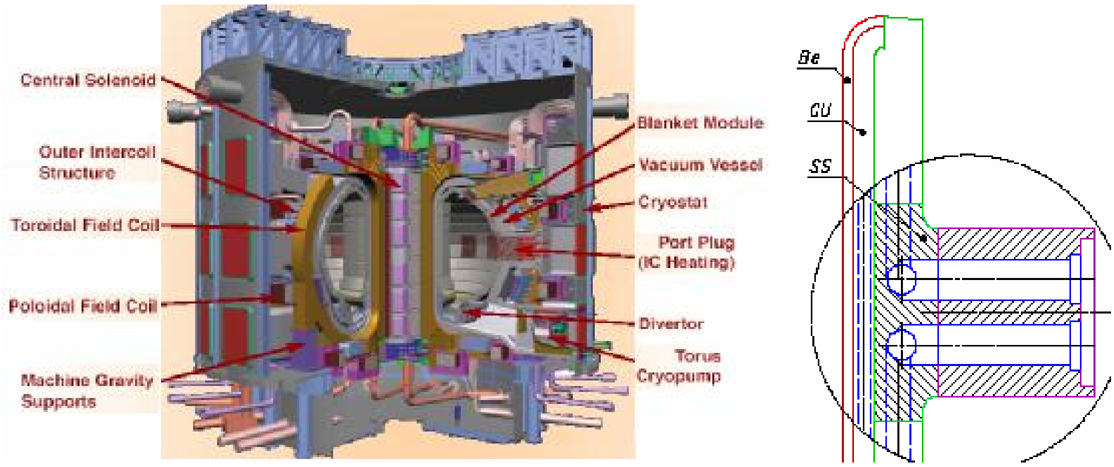


Figure 1. Structure of ITER and the Fist Wall

The ITER Blanket System comprises the plasma facing first wall (FW), shielding, and separate manifolds that provides the routing of cooling water. The FW panel is a composite metal structure including a SS carrier about 6 cm thick, a copper heat sink about 1 cm thick and a beryllium coat 1cm thick. It must be tested rigidly before use. Among detections, inspections of conjugation site, like bounding of two different objects and conjugation of two tubes, were difficult. Aimed at the question, three mock-ups were designed and tested using broad-band ultrasonic techniques. [1-2]

2. Feasibility studies on testing bounding quality of Be/Cu mock-up using broad-band ultrasonic inspection

C-scan water immersion ultrasonic test was employed to detect unbounding flaws of the mock-up. The mock-up was laid flat below the transfer, Be face up, and make sure sound beam incident vertically to the face. Figure 2 is diagrammatic sketch of water immersion ultrasonic test. After that, set the focal sport at faying surface of Be and steel, scan the mock-up and get C-scan image.

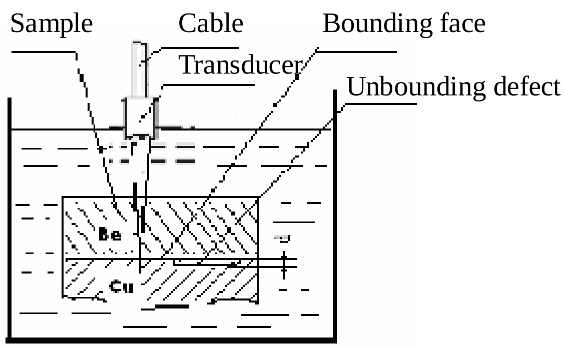


Figure 2 diagrammatic sketch of water immersion ultrasonic test

Propagation characters of ultrasonic in three-layer mediums were researched. Suppose middle layer is d thick. Reflection index of ultrasonic can be calculated according to foundation theories, just as figure 3.[3]

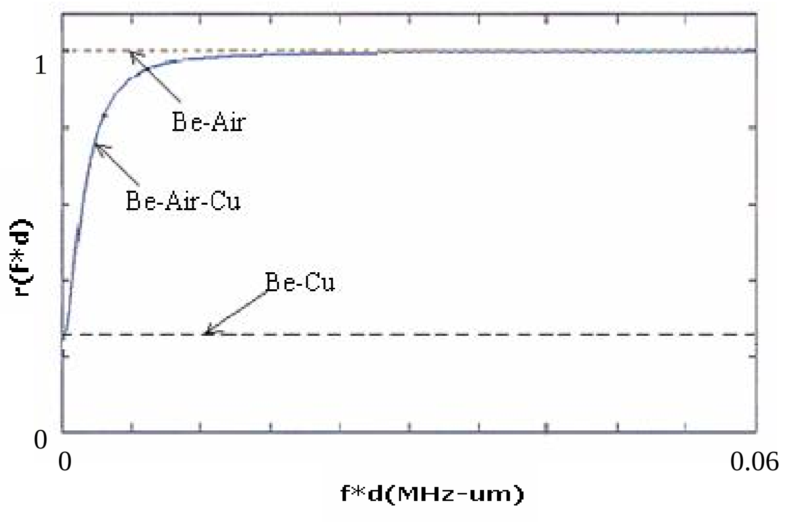


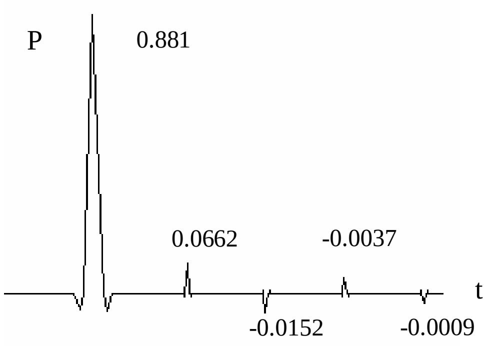
Figure 3 relationship of reflect amplitude and f*d

From figure 3, if the frequency of ultrasonic is 10MHz, while d was changing from 0 to 0.001um, the reflection was raising sharply from 0.27 to nearly 1. Due to this, ultrasonic test is capable of inspecting bounding defects.

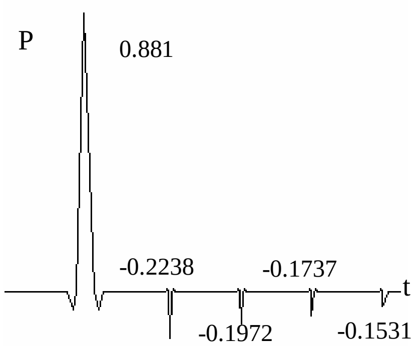
According to the theory, when ultrasonic propagates from one medium to another, it will reflect and penetrate on the interface.

$$r_{12}=\frac{z_2\text{-}z_1}{z_2+z_1}\quad , \quad t_{12}=\frac{2z_2}{z_2+z_1}$$

Here, z_1 and z_2 are acoustic impedance of mediums. When $r_{12}>0$, it represents that reflective wave has the same phase with incident wave. Otherwise, When $r_{12}<0$, they have the opposite phase. While acoustic impedance of Be is 2.35×107g/cm2 • s and Cu is 4.16×107g/cm2 • s. So we can calculate the fist echo wave, the second, the third and so on. Express it graphically in figure 4.



Theoretical waveform of bounding interface



Theoretical waveform of unbounding interface

Figure 4 theoretical waveforms of interfaces

Figure 4 shows that if two materials weld well, the echo positive value alternates with minus one. In contrast, the waveform of unbounding interface doesn't have this phenomenon. What will happen if it is partly bounding in focal spot? Suppose that A_B is bounding area in the focal spot whose area is A_E, and unbounding one is A_V, showed as figure 5.

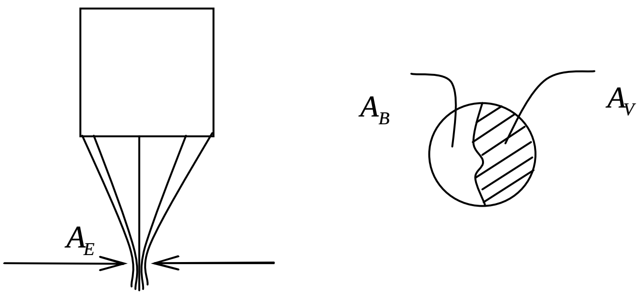


Figure 5 bounding message in focal area

The echo amplitude that the transducer detected (P) is algebraic addition of two parts. P=PB+PV. So P was deduced according to the foundimental theory as:

$$P=|[\frac{A_V}{A_E}(r_B+1)-r_B]\cdot P_{ref}\ |$$

Here, A_V/A_E represents unbounding ratio, and r_B is respection rato of bounding interface. While unbounding message usually used as reference, so P_{ref} is unbounding echo amplitude. Accordingly, real line in figure 6 was derived.

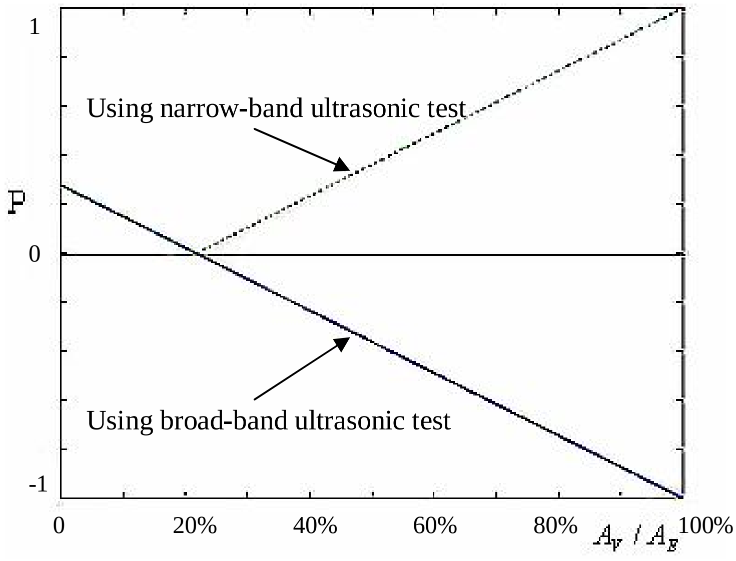


Figure 6 relations of echo amplitude and unbounding ratio

According to the figure 6, in this bounding quality test when unbounding rato is 19.8%, echo amplitude is 0; when unbounding rato is 0and or 39%, absolute value of echo amplitude is 0.242, but their phase are opposite. It is impossible to distinguish 0 from 39% if industral ultrasonic equipment was imployed. In contrast, it will easily be distinguished if broad-band ultrasonic instruments are applied. Generally speaking, broad-band ultrasonic apparatus can inspect defects range from0 to 100% instead of 39% to 100% using nomal ultrasonic equipment.

3. Be/Cu mock-up

Be/Cu mock-up were designed to test the bounding quality of Be and Cu. Generally speaking, Be is venomous and costly, due to this, we need something agreeable to replace it. As a consequence, Be which acoustic impedance is 2.35×107g/cm2.s was replaced by Sn which acoustic impedance is 2.39×107g/cm2.s, while Cu which acoustic impedance is 4.16×107g/cm2.s was replaced by steel which acoustic impedance is 4.16×107g/cm2.s. This replacement was operated according to the theory that the most important factor in ultrasonic test is acoustic impedance.

a

b

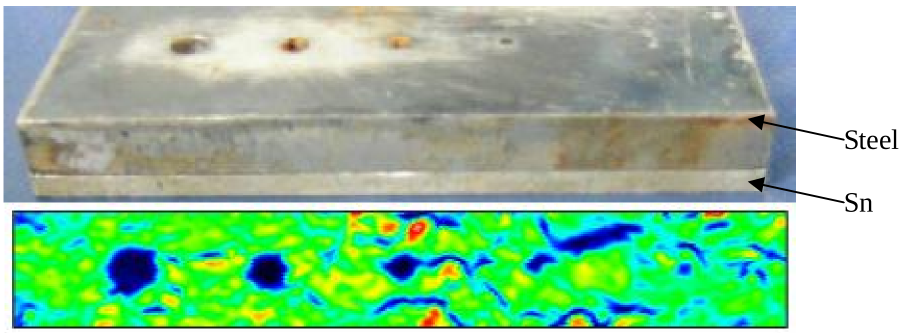


Figure 7 visible light picture & C-scan image of the Be/Cu mock-up

Figure 7 (a) is the picture of the Be/Cu mock-up. A row of holes were drilled as simulation defects in the steel, the diameters of which were 1mm、2mm、3mm、4mm、5mm. And then, a sheet of Sn was welded on to the steel. Set the focal sport at faying surface of Sn and steel scan the mock-up and get C-scan image as figure 7 (b).

The C-scan picture showed a clear bounding information about the Be/Cu mock-up. We can check out not only simulation defects but impersonal defects.

4. graphite/Cu mock-up

Some other experts put forward the suggestion of replace the Be with graphite. This is because graphite has good heat shock resistance which is very needed in ITER. The mock-up showed as figure8. Similar as Be/Cu mock-up, the graphite/Cu mock-up was made of graphite and steel.

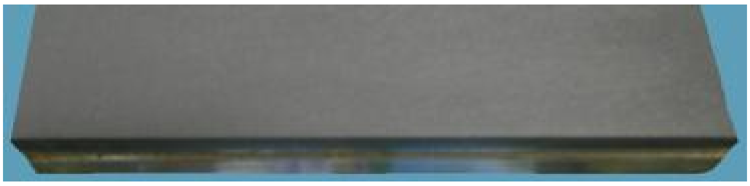


Figure 8 picture of the Graphite/Cu mock-up

Acoustic impedance of graphite is smaller than that of steel and bigger than that of air, so the echo from the graphite/steel interface has the same phase with that of the fist interface, shows as figure 9 (a), while the graphite/air interface shows a reverse phenomenon, shows as figure 9 (b).

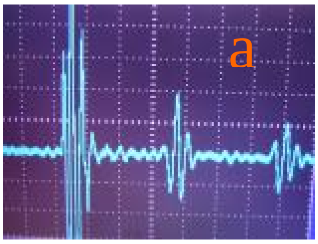


Figure 9 waveforms of bounding point (a) and unbounding point (b)

4. Cu/SS mock-up

Cooling passages are particularly dense in the FW where the surface radiation of the plasma and the neutron heating is strong. Bounding quality of Cu basic and stainless steel (SS) tube affects the cooling efficiency. As a result, it must be tested before use.

Because that the acoustic impedance of Cu is similar with that of SS, the mock-up was manufactured with SS tube. Holes with different diameters and different depth simulating as unbouding defects were designed in the mock-up.

Figure 10 the picture of mock-up and rotated acoustic mirror

Since the inspection must be operated in the tube, it was difficult to complete. To solve the problem, a rotated acoustic mirror device was developed. Figure 10 is the picture of mock-up and rotated acoustic mirror.

The mirror with an inclination of 45 degrees was polished and rotated under the motor's drive. Mirror tube was made of plexiglass whose sound transparent fulfills the experimental request. The transducer was fixed and translated the signals to ultrasonic instrument.

While doing experiment, insert the acoustic mirror into the mock-up, and put them in water together, just as figure 10 shows. Ultrasonic beam which is emitted from the transducer incidents vertically to mirror tube after reflection of the mirror. And then the beam penetrates the mirror tube and water around the rotated acoustic mirror, incidents to the interface of mockup. The transducer detects echo wave from mockup's interface, so that it can detect flaws. Echoes of mock-up, where we are interested in, can be read from figure 11.

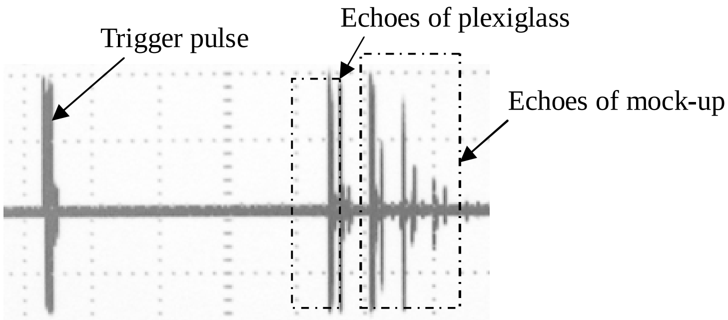


Figure 11 waveforms gained using the rotated acoustic mirror

5. Conclusions

◆ Ultrasonic C-scan test can check out areas as small as 1mm square. Automatic, fast, intuitive, 100% detection are characteristics of this method.

◆ Use of phase information can avoid misjudgments.

◆ In the SS / Cu Detection study, the probe has to come into the tube. So the acoustic mirror device was developed.

◆ In this paper, some of the test results is given in the form of waveform. If the digitized waveform realized, test results will be showed in images so that it will be more intuitive. The precision of test can be improved by a certain digital image processing.

Acknowledgment

This work has been supported by the project No. **KM200710028007**, **10502035, 2006CB605305.**

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