International Journal of Hybrid Information Technology
Vol. 10, No.2 (2017), pp. 153-162
http://dx.doi.org/10.14257/ijhit.2017.10.2.15

Acoustic Emission of Lead Components Simulating Feasibility of the Corrosion and Oxidation of Plutonium Materials

Junfeng Ma and Leiqi Zheng

Xinxiang Medical University.Henan.China
Corresponding E-MAIL:Majfeng@126.com

Abstract

Acoustic emission testing is a non-destructive testing method to detect the internal defects of materials by using the acoustic properties of the materials and their defects. Acoustic emission detection has been a hot spot in nondestructive testing, and acoustic emission nondestructive testing has the characteristics of reflection, refraction and waveform conversion at the interface. Through the analys of simulation results,ultrasonic pulse reflection method is feasible to detect corrosion defect and oxidation layer density change of lead components.By studying the similarity of lead and plutonium's acoustic characteristics, it is supported theoretical platform of radioactive plutonium components.The test used by lead material instead of plutonium material components was conducted by ultrasonic inspection. Software simulated lead oxide corrosion.

***Keywords**:Ultrasonic inspection;Simulation;Simulated sample;Oxidizing*

1.Introduction

Acoustic emission is transmitted to metal or defect interface, it will happen all or part of the reflection, so it is widely used in industrial inspection [1-4].Plutonium materials, such as nuclear material in the industry and the military have a very important application, but the nuclear material in the process of storage, there will be sparkling, oxidation and other characteristics, storage time is longer, the density will change. Because of the strict management of radioactive material, the human body has direct ionizing radiation, so it is not easy to measure directly, and the radioactive material of plutonium is radioactive damage to the measuring instrument [5-6].

In view of this, this paper analyzes the corrosion and oxidation characteristics of lead based multilayer metal structure by acoustic emission experiments. Through the study of its oxidation corrosion characteristics, the feasibility of the corrosion and oxidation of plutonium materials by acoustic emission experiment is studied. It is an experimental basis for the next step to understand the oxidation law of plutonium and its corrosion mechanism.

Alternative Theoretical Basis for the Selection of Lead Aluminum Steel

In order to obtain better simulation results, the echo signals of the simulation interface and the actual plutonium material are as far as possible. By theoretical calculation, the acoustic emission propagation time, interface reflectivity and transmittance of the lead instead of plutonium and aluminum in place of beryllium are similar, and the calculation process is as follows.

1.1 calculation of transmission

The velocity of longitudinal wave in infinite medium

$$C_l = \sqrt{\frac{E}{\rho}\frac{1-\sigma}{(1-2\sigma)(1+\sigma)}} = \sqrt{\frac{K+\frac{4}{3}G}{\rho}} \quad (1)$$

ISSN: 1738-9968 IJHIT

Shear wave velocity in infinite medium is

$$C_t = \sqrt{\frac{E}{\rho}\frac{1}{2(1+\sigma)}} \quad (2)$$

The calculated results are shown in Table 1

Table 1. Acoustic Parameters of Metal Components

Material	Density	Sound		Elastic constant			
		P	Transverse wave	Young's modulus	Shear modulus	Poisson's ratio	Bulk modulus
Plutonium	19.71	2364	1465	10.08	4.23	0.186	5.34
Beryllium	1.86	12890	8880	31	14.7	0.05	11.48
Steel	7.91	5790	3100	19.7	7.57	0.30	16.42
Lead	11.4	4150	2348	1.7	0.27	0.36	20.24
Aluminum	2.7	4087	3000	6．9	0.42	0.42	143.75

Metal impedance calculation formula is:

$$Z=\rho C \quad (3)$$

Impedance of each material is shown in Table 2

Table 2. Impedance Parameters of Metal Components

Material	Plutonium	Beryllium	Lead	Aluminum	Steel
Impedance×105（g/cm2.s）	46.598	23.975	24.738	16.902	45.799

Reflection coefficient is:

$$R_I = R_a^2 = \left(\frac{Z - Z}{Z + Z}\right)^2 \quad (4)$$

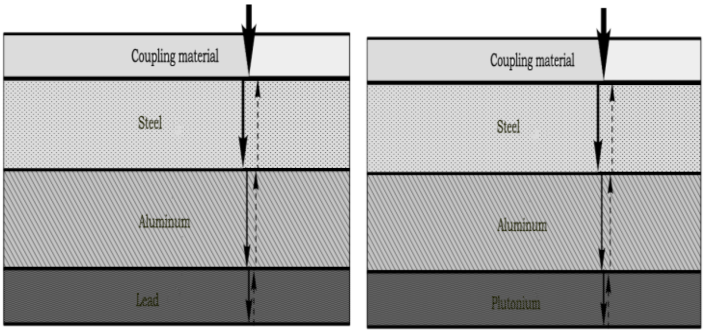
Transmission coefficient is: $T_I = 1 - R_I$ （5）

The results are shown in table 3:

Table 3. Material Results

Material	beryllium and steel	Plutonium and beryllium	aluminum and steel	lead and aluminum
Reflection coefficient	0.0978	0.1028	0.2085	0.0344
Transmission coefficient	0.9022	0.8972	0.7915	0.9656

The longitudinal wave into the plutonium components and the lead components are shown in Figure 1. As can be seen from the calculation results, the plutonium beryllium components after two acoustic reflection and transmission of acoustic energy into the air can reach 80.95%. The energy loss rate of lead aluminum materials was 76.46%, so difference of calculation results was 5.5%.Therefore, from the point of view of the energy loss , both results are relatively are close.



Plutonium components (b)Lead component

Figure 1. Schematic Diagram of Vertical Incedent to Components of Longitudinal Wave Calculation of Transmission Time

Assuming that the thickness of the aluminum is X mm, transmission time is:

$$\frac{X}{6.29\times 10^{6}\ mm/s}=\frac{7\ mm}{12.81\ mm} \qquad (6)$$

Thus the X was calculated to be 3.4mm. In the same way, the thickness of lead is 6.5mm, and the results are as shown in Table 4.

Table 4. Material Parameters

Material	Longitudinal wave velocity (×103m/s)	Density (×103kg/m3)	Thickness (mm)
Beryllium	12.81	1.86	7.0
Aluminum	6.29	2.70	3.4
Plutonium	2.34	19.71	7.0
Lead	2.17	11.40	6.5

Simulation analysis：

The acoustic emission is used to detect t the defect area, and the typical waveforms are shown in Figure 2 And Fig 3. simulation results show that the corresponding diameter is 15mm, the depth of the 2mm defect area.

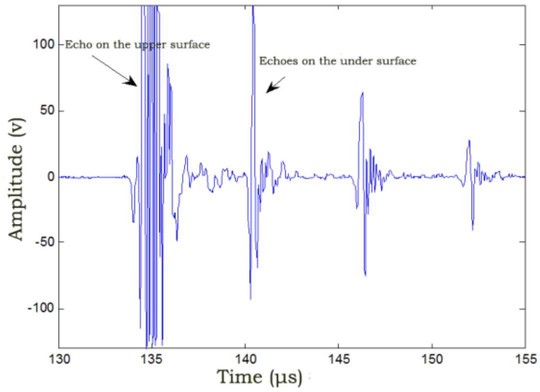


Figure 2. AE Signal of Normal Area

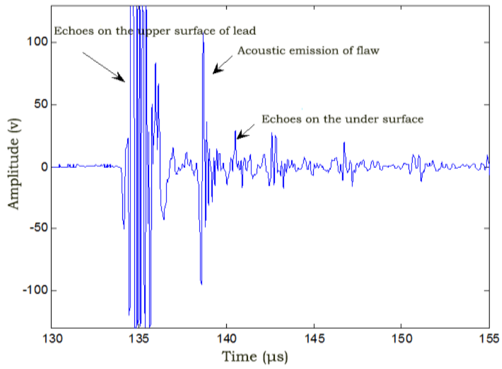


Figure 3. AE Signal of Defect Area

The comparison between the 7 and 8 can be seen that the acoustic emission echo signal of the sound area and the defect area are quite different. Compared to intact waveform waveform, defect area corresponds to the grids on the surface echo and echo of surface much wave of a defect and tinplate surface echo amplitude significantly reduced.

The figure 8 further analysis, defect echo and echo of surface and the time difference is 1.8 Mu s, acoustic emission in stereotype propagation velocity is about 2.1mm/ microsecond, the calculated defect depth is about 1.95mm. The actual defect depth is 2mm, the error is about 2.5%.

From the above analysis, we can find that the corrosion defects can be detected by using A scanning method. In the intact zone, the grids on the surface echo and echo of surface and no other echo signal; and in the defect area, between grids in the upper surface and the lower surface of the echo will appear flaw echo signals, through between the defect echo and echo of surface and bottom time difference can determine the depth of corrosion defects.

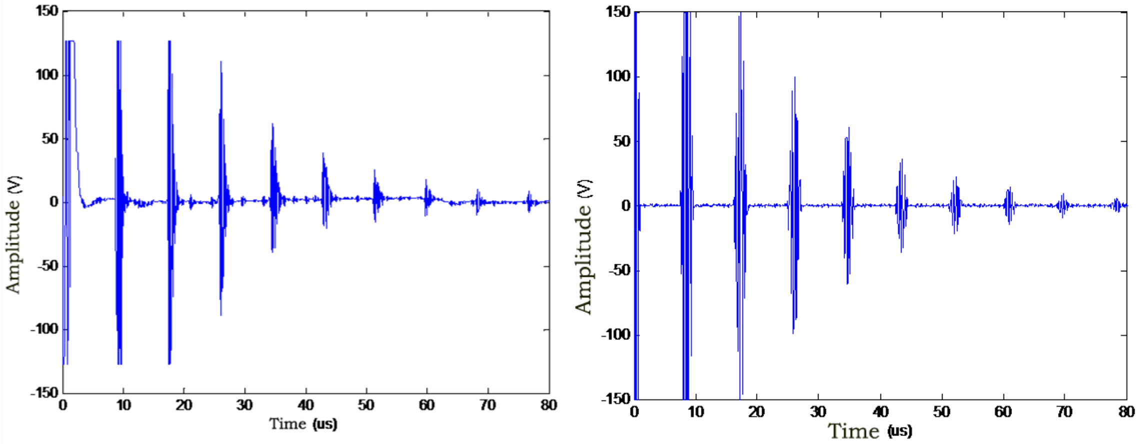
The results and analysis of 3 components simulation test results

simulation program verification test

According to the test , the echo waveform of the standard test block is shown in Figure 4(a), and the simulation results are shown in Figure 4 (b). The time when the first five echo peak appeared, the results are listed in table 5.

Table 5. Echo Peak Time of the Actual Value and Simulation Value

Measurement times	Once echo	Second echo	Third echo	Fourth echo	Fifth echo
Measured value（μs）	8.92	17.6	26.04	34.48	42.92
Simulation value（μs）	8.68	17.4	26.12	34.88	43.56
Relative error（%）	2.7	1.1	0.3	1.2	1.5
Mean error（%）			1.4		



（a）（b）

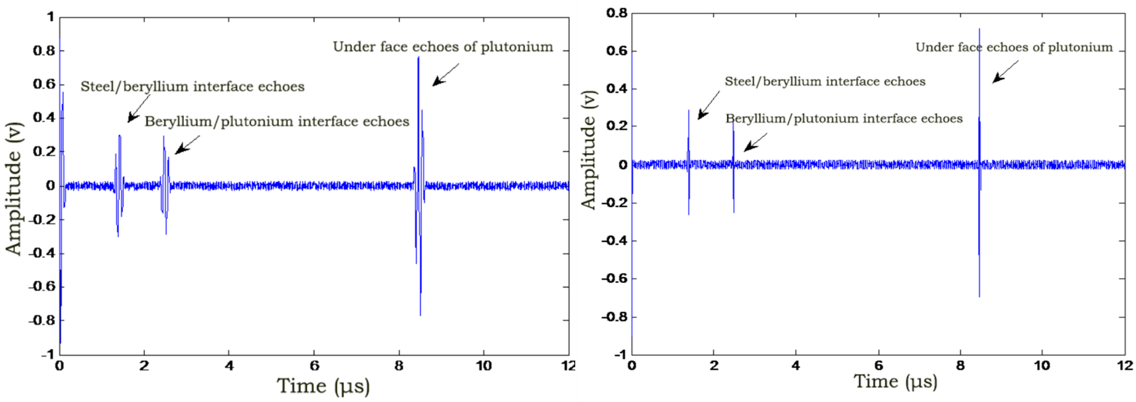
Figure 4. The Simulation Results (a) Actual Testing Signal Waveform (b) The Simulation Waveform

From Figure5 and table 5 it can be seen that the waveform and the actual waveform are basically the same. The average error is 1.4%. The simulation program is obtained by simulation is correct.

Components Simulation Test Results and Analysis

Simulation test of acoustic emission in the intact state

When the components are in good condition and the internal defect free, the f is used to simulate the acoustic emission of 10Hz, and the signal waveform is shown in Figure 8. The pulse duration number n is 3, and the sampling frequency of FC was 250Hz.



(a) (b)

(a)f=10Hz，n=3，fc=250Hz（b）f=50Hz，n=3，fc=250Hz

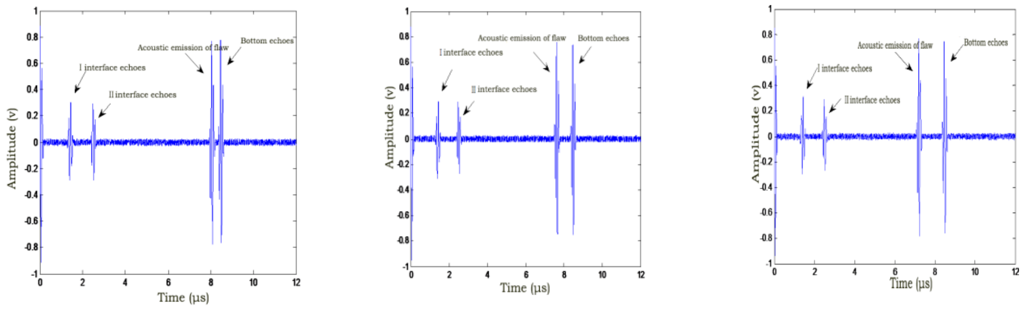
Figure 5. Components in Good Condition under the AE Testing Signal Simulation Waveform

when the components are not defective, there are mainly three echo signals in the signal, respectively: the steel / beryllium interface echo signal (called the first interface echo), beryllium / lead interface echo signal (called the second interface echo) and lead at the bottom of the echo signal (called the bottom wave). If the frequency of the acoustic emission is increased, and the position of the echo on the time axis is not changed. But the echo width of each interface is narrow, it is beneficial to distinguish the interface wave and the defect wave.

Simulation test of lead layer in component

Simulation test for detection parameters constant and the depth different of defect corrosion

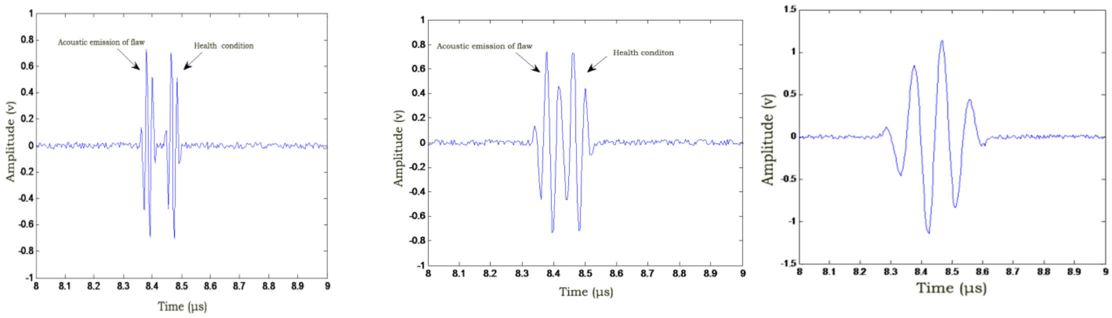
The acoustic emission frequency is f=10Hz, the pulse period is n=3, the sampling frequency is fc=250Hz. The simulation waveforms of 0.5mm, 1mm and 1.5mm in the depth of corrosion defects are shown in Figure 6(a), (b), (c), respectively.



(a) (b) (c)

(a) Defects depth of 0.5mm (b) Defects depth of 1mm (c) Defects depth of 1.5mm

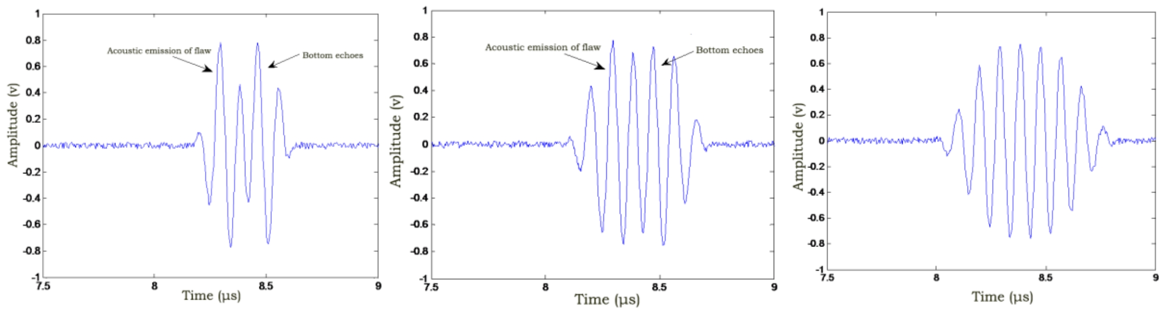
Figure 6. Different Corrosion Depth Simulation Testing Waveform



（a）f=10Hz （b）f=25Hz （c）f=50Hz

Figure 7. Simulation Testing Waveform of Different AE Frequency

From Figure 7 it can be seen that the acoustic emission detection capability of different frequencies is different for the same defect. In Figure 8 (a), the defects of the defects are not separated from the base wave, so the defect can not be detected, and the gap between the defect and the wave is gradually separated with the increase of the acoustic emission frequency. The bigger distance between defect wave and bottom wave is , the more it is to detect, so the ability of detecting the minimum defect can be improved by increasing the acoustic emission frequency.



（a） (b) (c)

（a）n=3（b）n=5（c）n=7

Figure 8. Simulation Testing Waveform of Different Ultrasonic Frequency Cycles

The depth of corrosion depth is 0.2mm, the acoustic emission frequency is f=10Hz, the sampling frequency is fc=250Hz, the pulse duration is 3, 5, 7, and the simulation results are shown in Figure 9.

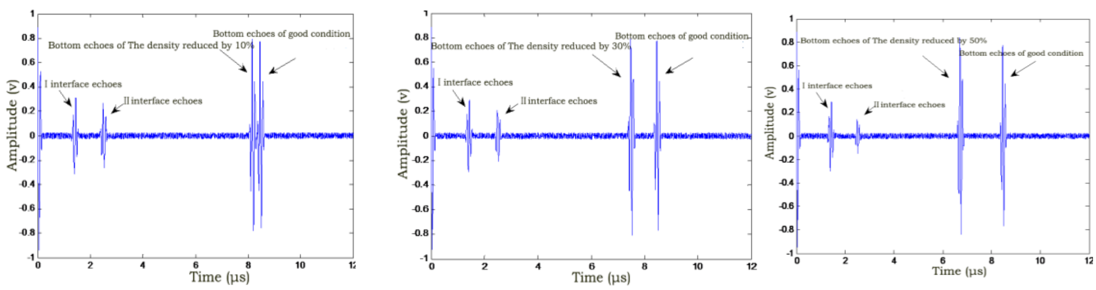
From Figure 9, it can be seen that the acoustic emission pulse duration (i.e., pulse width) is also affected by the same defect. With the increase of the pulse width, the defects in the 11 (c) of the defects are not separated from the bottom wave, which can not be detected.

Simulation test of lead layer material density of components

When lead is oxidized, the volume density will be reduced, and the metal surface oxidation corrosion can be analyzed by simulating the wave of the metal.

Simulation and detection of lead layer material density as a whole

AE frequency f = 10Hz, pulse period n=3, sampling frequency 250Hz, when lead layer material density is reduced by 30%, 10%, 50%, the simulation test waveform is shown in Figure 9.



(a) (b) (c)

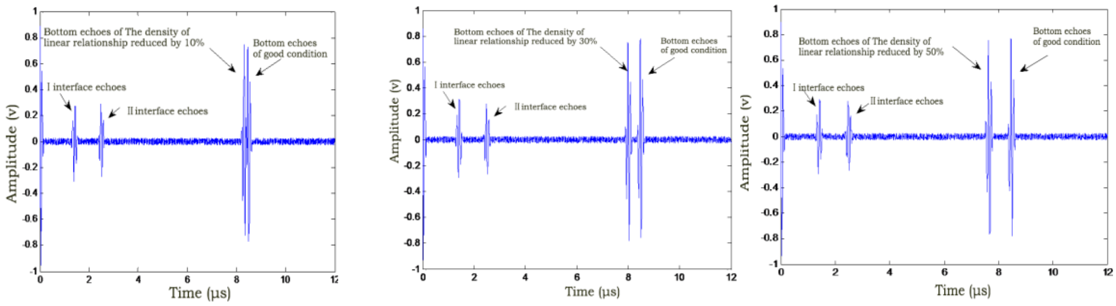
(a)density decreasing by 10% (b)density decreasing by 30% (c) density decreasing by 50%

Figure 9. Plutonium Material Density Changes of the Simulation Waveform

From Figure 10 it can be seen that the position of the bottom wave and the amplitude of the second interface echo in the signal can be changed when the density of the material is changed. Compared with the intact state, when the density decreases, the bottom wave position will move forward, and the second interface echo amplitude will decrease. The greater the density decreases, the more II interface echo amplitude decreased significantly. Therefore, the change of the position of the bottom wave and the change of the amplitude of the second interface echo can be determined by the change of the density of the inner material.

Simulation test of the density of lead layer

AE frequency f = 10Hz, pulse period n=3, sampling frequency 250Hz, When the material density along the thickness direction according to the linear law were reduced by 30%, 10%, 50%, the simulation test waveform is shown in figure 10



(a)density decreasing by 10% (b)density decreasing by 30% (c) density decreasing by 50%

Figure 10. Plutonium Material Density According to the Linear Change of the Simulation Waveform

From figure 10 it can be seen that when the density of the inner layer of the inner layer is changed, the position of the bottom wave will be changed. Compared with the intact state, when the density decreases, the bottom wave position will move forward. The greater the density decreases, the greater the degree of bottom wave forward, so the change of the inner material density can be determined by the change of the position of the bottom wave. The difference between the material density and the whole change is that the echo amplitude of the second interface is essentially unchanged, and the amplitude of the second interface echo decreases with the decrease of the density.

Conclusions

It is feasible to detect defects of plutonium components and detect the density change of the plutonium components by the acoustic emission method. Acoustic emission parameters have an effect on the detection capability, and the ability of detecting the minimum corrosion defects can be improved by increasing the acoustic emission frequency and decreasing the pulse width. The existence of corrosion defects can be judged by observing whether there is a defect echo between the end of the acoustic emission signal and the bottom wave. At the same time, the change of the inner material density can be judged by the position change of the bottom wave in the time axis: bottom wave to move forward more, the density of the material to decrease more.Because the density of plutonium materials is larger than that of lead, the acoustic emission shows that the distance between the defect and the bottom wave is smaller than that of the lead.. This research conclusion provides a theoretical platform for the research on nondestructive testing of plutonium materials.

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Authors

Junfeng Ma, assisted professor, Research direction: Acoustic emission