Method for Detecting Multi-Modal Vibration Characteristics of Landmines

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Abstract: The acoustic vibration characteristics of landmines are investigated by means of modal analysis. According to the mechanical structure of landmines, a certain number of points are marked on the landmine shell to analyze its multi-modal vibration characteristics, based on laser self-mixing interferometer and taking 69 plastic landmine as an example, the vibration detection experiment system is built to show the results of analytical method of multi-modal testing. The first and second order natural frequencies of the bricks are 38 HZ and 106 HZ, 112HZ and 232HZ for plastic landmines, and 74HZ and 290HZ for metal landmines. The first and second order natural frequencies of the bricks are far smaller than those of plastic landmines and metal landmines. This indicates that landmines show multi-modal vibration characteristics under external excitation, which are significantly different from those of bricks. The findings can be used for further research on acoustic landmines detection technology.

Key words: Multi-Modal Vibration; Natural Frequency; Vibration Mode; Acoustic Landmines Detection

1 Introduction

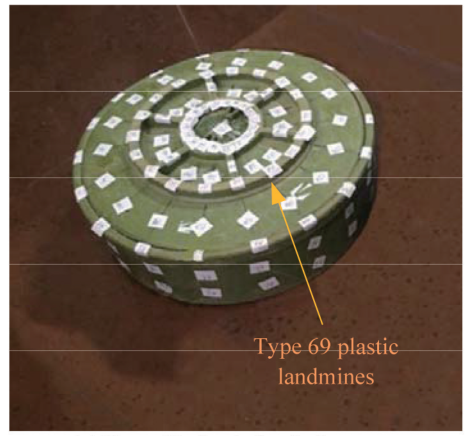
Safety and effectiveness in detection of landmines have always been great challenges for mine clearance experts. Commonly used metal detectors, based on the principle of electromagnetic induction, can only detect metal landmines, but they have poor performance in detecting non-metallic landmines such as plastic ones with very little metal content. Other imaging techniques, such as infrared, ground penetrating radar and x-ray, are ineffective to distinguish landmines from other buried objects such as rocks, bricks or other debris in the detection mechanism[1-2]. Neutron analysis technology, which can be employed to identify landmines by detecting the chemical characteristics of explosives[3-4], has a strong capability to identify landmines in theory, but the system is extremely complex apart from its weak detection signal. In the study of new landmine detection methods and mechanisms, the acoustic resonance technique, based on the mechanical characteristics of landmines (with big acoustic compliance or flexibility) and the principle of acoustic-seismic coupling[5], excites the resonance effect of landmines and the soil above them by emitting high-energy low-frequency sound waves to the surface, thus, making obvious and unique changes in the vibration state of the earth's surface, based on that, the existence of landmines can be distinguished.

Acoustic resonance technology is especially suitable for the safe and reliable detection of non-metallic mines, but it is very complicated as the detection signals are affected by the properties of landmines and soil and their interactions. Since 1999, Professor Sabatier and Dr. Donskoy have studied linear and nonlinear resonance phenomena of "soil-landmine" system based on the characteristics of low-frequency acoustics using the method of lumped-parametric system modeling[6-9]. Then, Dr. Yu has explored the anti-resonance mechanism of landmines[10]. Dr. Zagrai has studied the impact of buried soil on the vibration characteristics of landmines from the perspective of modal analysis[11]. In the experimental research of acoustic landmine detection, Sabatier et al. proposed a surface vibration detection system based on laser Doppler vibrometer[12]. Robert et al. studied long-distance acoustic wave emission system based on acoustic parametric array[13], and Kasban et al. studied the algorithm for automatic identification of landmines with graphic grayscale and intensity[14]. The above studies verify the feasibility of acoustic resonance technology for landmine detection, but there is still a long way to go to put them into practice. The detection of landmine´s acoustic characteristics is an important research direction in the development of acoustic landmine detection engineering system.

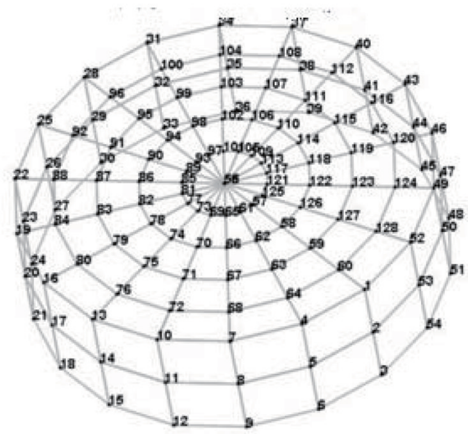
In recent years, the study of acoustic resonance technology for landmine detection has carried out. Literature[15] described the basic principle of acoustic-seismic coupling technology for landmine detection and the analytical method of "soil - landmine" resonance model, and literature[16-18] described the experimental system and method and identification capability of acoustic wave technology for landmine detection. Based on method analysis for detecting multi-modal vibration characteristics of landmines, an experimental system based on laser self-mixing interference is built to detect the modal parameters of the landmine such as natural frequency and multi-modal vibration modes, and analysis are done in comparison with bricks and other buried objects. This paper provides a theoretical basis and theoretical model for the experimental study of acoustic resonance system for landmine detection.

2 Experimental Test Plan for Detecting Multi-Modal Vibration Characteristics of Landmines

Fig. 1 shows the experimental object and analysis model of the modal test. Type 69 plastic landmines with plastic shell (hereinafter referred to as plastic landmines) are taken as the example to illustrate the modeling method of multimodal test. The striking force points are marked on the surface of the plastic landmine model. According to the structure of the plastic landmine, the upper surface of the plastic landmine is divided into 18 equal parts and 5 circles,



(a) Type 69 plastic landmine



(b) Modal analysis model

Fig. 1 Modal Analysis Model of Type 69 Plastic Landmines

and the plastic landmine is divided into 3 equal parts on the side. A total of 127 points (including the central point) are marked and numbered, and the bottom of the landmine is glued to the rigid platform with foam. A pulsed hammer is used to strike the points marked on the surface of the landmine model to generate an impact force $f(t)$ excitation with a width of t, which is processed and analyzed by a modal analyzer to obtain a vibration response transfer function between the excitation point and the central point, and a modal shape of the landmine shell. According to the Maxwell's principle of anisotropy, the response of point P caused by the input of point Q is equal to that of point Q caused by the same input at point P. Therefore, upon excitation at each marking point, the vibration response detected at the center point is equivalent to that detected at the other excitation points upon excitation at the central point. In the process of measurement, the laser always keeps the best focusing state, displays the time domain and frequency spectrum diagram of vibration signal and reference signal on a real-time basis, and completely records the frequency spectrum information of every measured point and the vibration mode of the measured surface.

The model test plan of landmine is studied as below based onthe study of the test method for the above modal analysis. By using the pulse hammer excitation method, a plurality of knock force points are arranged on the landmine shell. By applying some dynamic excitation to the landmine shell, the excitation force signal and the vibration response signal of each point are collected, and modal parameters are obtained by using a parameter identification method according to the relationship between the excitation force and the response signal. Fig. 2 shows the experimental system for multi-modal vibration mode measurement designed in this paper, including the experimental object, force hammer, data acquisition system, modal analyzer, laser vibrometer and PC terminal. Prior to the experimental test, the excitation pulse hammer (force hammer) is connected to the data acquisition system, the position of the laser vibration detector is adjusted, so that the center point of the laser is aligned with the center point of the landmine. Then select the focus distance is selected according to the distance between the landmine center point and the laser emission point, the mode analyzer is adjusted and the data acquisition system is connected with the mode analyzer and the PC terminal. The test object is knocked with the force hammer to generate force signal, avoiding continuous percussion when knocking. The pulse hammer needs to be as vertical as possible with the percussion surface. The outermost marking points on the surface of the landmine should be knocked once in horizontal and vertical directions respectively because they are in the intersection of two planes. The data acquisition system collects the force signal generated and the laser vibrometer detects the vibration displacement signal of the measured point. The laser vibrometer and the data acquisition system are connected with the modal analyzer to input the vibration signal collected through scanning into the modal analyzer, then the modal parameters of the landmine such as natural frequency and vibration mode are demodulated, finally, the demodulated data are further processed and displayed by a PC terminal. Specifically, VSM1000L-EXT-SCAN laser vibrometer produced by Julight S.R.L (an Italian tech company) is used. Based on the principle of self-mixing interference, the laser vibrometer overcomes the disadvantages of traditional interferometric testing equipment, such as complex equipment, bulky system, hard beam collimation and inconvenient to carry, it can accurately measure the contactless vibration signal on the rough divergent surface. After the light output by the laser is reflected or scattered by an external vibrating object, part of the light is fed back to the inner cavity of the laser, and the light fed back carries the vibration information of the target, then the output signal of the laser is modulated to form self-mixing interference, and the vibration signal of rough surface is detected through demodulation.

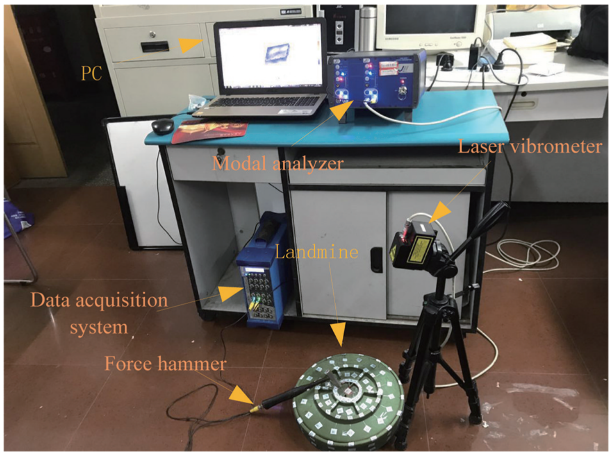


Fig. 2 Multi-Modal Vibration Mode Testing System for Landmines

3 Results Analysis and Discussion

Based on the above test methods and test systems, comparative analyses are done on the natural frequencies and modal formations of plastic landmines (Type 72 anti-tank landmine and Type 69 anti-infantry landmine) and bricks. Fig. 3 is the measured vibration mode diagram of plastic landmine (the unit of illustration is millimeter, the same below). According to Fig. 3, the maximum value of the first amplitude of landmine is near 112HZ, and corresponding to the first-order natural frequency and the first-order modal vibration mode of plastic landmine, the natural frequency is 112 Hz and the amplitude is -73dB. The second-order mode of plastic landmine appears at the frequency of 232HZ, corresponding to the second-order natural frequency, with an amplitude of -84dB. The third-order mode appears at the frequency of 723Hz, corresponding to the third-order natural frequency, with an amplitude of -96dB.

Fig. 4 is a measured mode diagram of Type 72 anti-tank landmine (metal landmine). According to Fig. 4, the maximum value of the first amplitude of metal landmines is around 74 Hz, and corresponding to the first-order natural frequency and the first-order modal vibration mode of metal landmine, the natural frequency is 74Hz and the amplitude is -80dB. The second-order mode of metal landmine appears at the frequency of 290Hz, corresponding to the second-order natural frequency, with an amplitude of -91dB. The third-order mode appears at the frequency of 686Hz, corresponding to the third-order natural frequency, with an amplitude of -95dB.

Fig. 5 is a measured mode diagram of Type 69 anti-infantry landmine (AP landmine). According to Fig. 5, the maximum value of the first amplitude of AP landmine is about 35Hz, and corresponding to the first-order natural frequency and the first-order modal vibration mode of the AP landmine, the natural frequency is 35Hz and the amplitude is -70dB. The second-order mode of AP landmine appears at the frequency of 74Hz, corresponding to the second-order natural frequency, with an amplitude of -71dB. The third-order mode appears at 113Hz, corresponding to the third-order natural frequency, with an amplitude of -73dB. The fourth-order mode appears at 179Hz, corresponding to the third-order natural frequency, with an amplitude of -70dB.

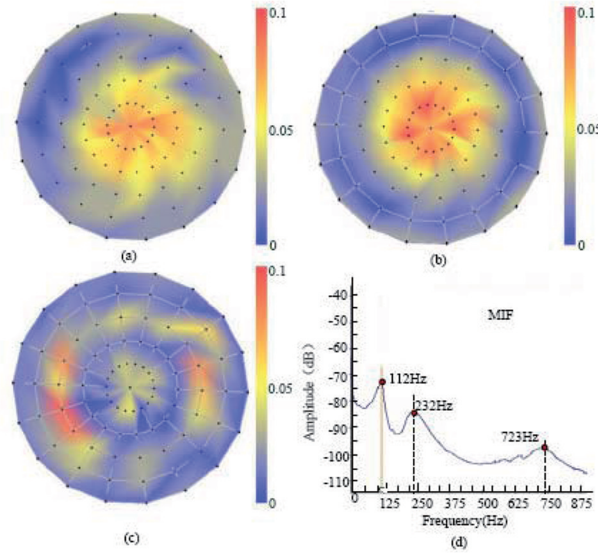


Fig. 3 Modal Vibration Characteristics for Plastic Landmines: (A) First-Order Mode Shape, (B) Second-Order Mode Shape, (C) Third-Order Mode Shape, (D) Modal Indication Function

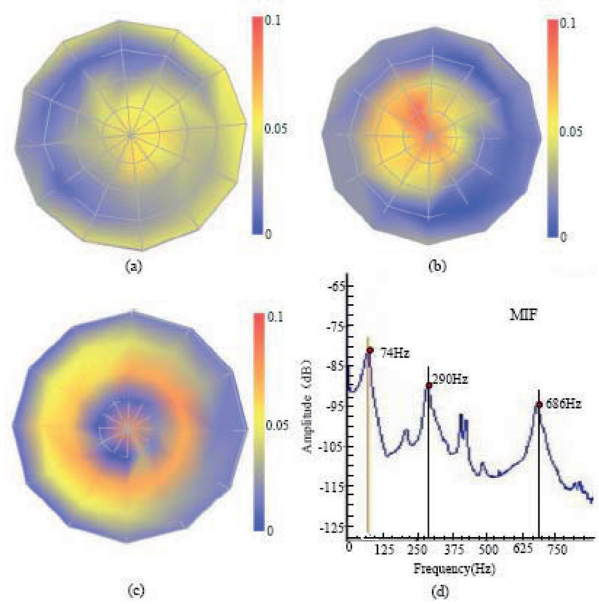


Fig. 4 Modal Vibration Characteristics for Metal Landmines: (A) First-Order Vibration Mode, (B) Second-Order Vibration Mode, (C) Third-Order Vibration Mode, (D) Modal Indication Transfer Function

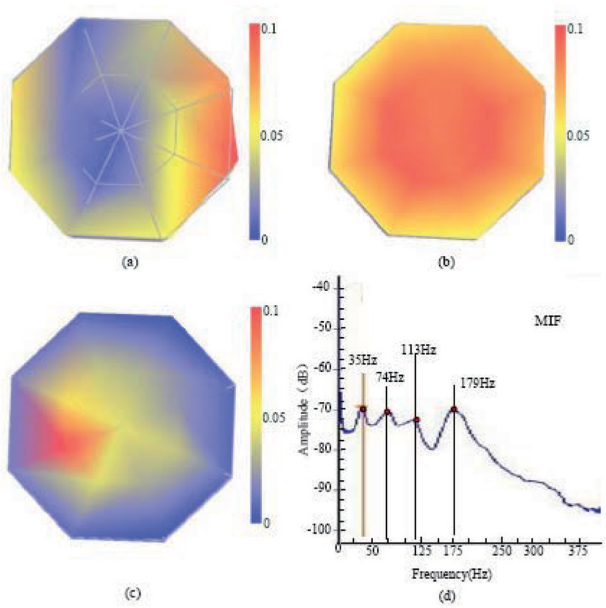


Fig. 5 Modal Vibration Characteristics for Ap Landmines: (A) First-Order Vibration Mode, (B) Second-Order Vibration Mode, (C) Third-Order Vibration Mode, (D) Modal Indication Transfer Function

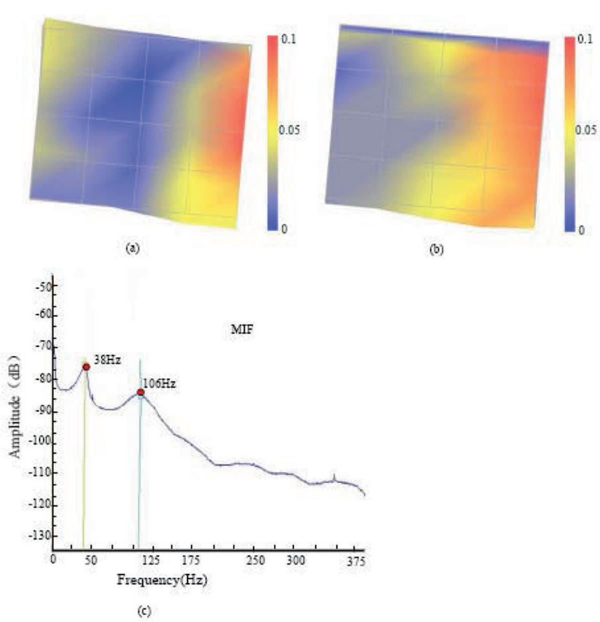


Fig. 6 Modal vibration characteristics for bricks: (a) First-order vibration mode, (b) Second-order vibration mode, (c) Modal indication transfer function

Fig. 6 is the measured brick vibration mode diagram. It can be seen that the maximum value of the first amplitude of the brick appears near 38Hz, which corresponds to the first-order natural frequency of the brick, and the corresponding vibration mode of the brick is the first-order vibration mode, corresponding to the amplitude of -75dB. The second-order mode of the brick appears at the frequency of 106Hz, corresponding to the second-order natural frequency, with an amplitude of -85dB.

By comparing with the vibration mode diagrams of landmines, the following conclusions can be drawn:

(1) The first-order natural frequency of brick is 38HZ, and the second-order natural frequency is 106HZ; the first-order natural frequency of plastic landmine is 112HZ, and the second-order natural frequency is 232HZ; the first-order natural frequency of metal landmine is 74HZ, and the second-order natural frequency is 290HZ. It can be seen that the natural frequencies of each order of brick are much smaller than those of plastic landmines and metal landmines.

(2) Due to the large flexibility of plastic landmine, the amplitude of brick is obviously smaller than that of plastic landmine on the whole. The different modal vibration modes of landmines have obvious characteristics, while the high-order modal vibration modes of brick are difficult to excite.

(3) The first-order natural frequency and corresponding amplitude of brick are similar to those of AP landmine, but the modal vibration modes of brick at each order show obvious differences from AP landmines. The vibration modes of brick do not vary obviously compared with those of AP landmines. The reason lies in that the rigidity of brick is larger than that of the landmine. Under given modal quality, when the external excitation frequency increases, the mode shape of the system changes as the amplitude decreases, but the change is relatively small compared with landmines. In addition, the amplitude change of AP landmine is smaller than that of brick.

(4) The vibration of the landmine under the external excitation is the result of superposition of the modes at all orders, and the main contribution to the vibration comes from the vibration modes of landmine at of the first few orders. The first-order modal vibration mode is the most significant, followed by the second order, and the other modes mostly show the local vibration of the landmine structure, and their contribution to the whole vibration is relatively small.

4 Conclusion

In this paper, an experimental test system for vibration detection is built based on VSM1000L-EXT-SCAN (Julight S.R.L), a number of striking force points are arranged on the shell of landmine by using the pulse hammer excitation method, and modal parameters such as natural frequency and vibration mode are obtained according to the relationship between excitation force and response signal. Taking the Type 69 plastic landmine as an example, the theoretical analysis of the experimental plan is carried out to expound the testing process of the experimental system. The results show that the first-order and second-order natural frequencies of bricks are 38Hz and 106Hz, those of plastic landmines are 112Hz and 232Hz, those of metal landmines are 74Hz and 290Hz, and those of AP landmines are 35Hz and 74Hz. The natural frequencies of bricks at the first and second orders are far less than those of plastic landmines and metal landmines, and the modal vibration modes of bricks and AP landmines show slight difference. The high-order modes are difficult to excite for bricks, and the modal characteristics of different landmines are also different. In general, the paper provides a theoretical and experimental basis for the research of acoustic landmine detection technology, it also illustrates the complexity of the vibration characteristics of landmines.

ACKNOWLEDGMENT

The project is supported, in part, by the National Natural Science Foundation of China (Grant No.61773249), the Natural Science Foundation of Shanghai (Grant No. 16ZR1411700), and the Science and Technology on Near-Surface Detection Laboratory (Grant No. 6142414090117, TCGZ2017A006).

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