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Study on Target Information Recognition Method of Acoustic Detection Array

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Abstract

Aiming to the traditional acoustic detection array with measuring the target coordinate, the accuracy of measurement data is affected by the propagation velocity of the acoustic pressure. This paper proposes a new measurement method, which obtain the mathematical model of the target parameter information when the target passing through acoustic sensor array based on acoustic array structure establish. From the model the target parameter information is just associated with the respective probe element's delay time of the acoustic pressure when the target passing through the acoustic detector, thereby it is effective to avoid the measurement accuracy influence from acoustic pressure velocity of the target parameter information. In order to obtaining the signal characteristics when the target passing through acoustic detector array, it would adopt time-frequency transform method to analyzed signals of the target through the acoustic array. By the simulation experiment it can improve the measurement precision of the target parameters information, and get frequency-domain characteristics of target information based on the measured analog signals of acoustic pressure. The result is benefit to enhance precision of target parameter information from acoustic array detection system, and it has certain guiding significance for the study of acoustic array structure.

Keywords*: acoustic detection, array structure, time-requency domain transform, information identification*

1. Introduction

The target position information is often measured by photoelectric test methods. Yet this method would bring disturbing by luminous flux change of non-target information and affect the parameter measurement of target position information. Using acoustic detector it can effectively avoid such matters, designing model of acoustic positioning is a major factor affecting the sound array measurement accuracy[1,2]. The common measurement array structures are linear array, planar array and three-dimensional array *etc.*

The past measurement method is solving mathematical models via bring a series of parameter as acoustic velocity into objective parameter, and obtain measure information. However under reality measurement, the actual sound velocity of propagation is not ideal velocity—340m/s due to the constraint of the measurement environment. In order to avoid the measurement error by using the speed of sound propagation directly, some researchers adopt neural networks method. It is helpful for calculating target information, while it is need to input measurement sample and training neural network for a long time, thus the

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method is somewhat complex[3,4,5]. In order to improve measurement precision test network structure is introduced, that would weakening the measure impact from the sound velocity and improve the test accuracy by lead into multiple measure points. While the experiment found that the effect of the mesure method is not very obvious, and it will increase the testing work and testing cost [6,7].

Based on how to avoid the measurement impact of the sound pressure velocity to the target parameters testing,the paper build an acoustic array model of an equilateral triangle consists of six sound pressure sensors, that analyze the acoustic detection array, get calculation model of the target parameters, and simulate the elements affecting location accuracy. Meanwhile in order to research the acoustic signal characteristics generated by the target passing through the acoustic sensor array, the paper collect the analog signal to analysis spectrum, and obtain the spectral characteristic of the target signal under different conditions.

2. The Principle of Acoustic Pressure Detection

When the test target fly at high speed, the surround air is sluggish inertia and disturbance spread too slow, so the gas is compressed and produces a centralized strong disturbances. The main reflection is that the air pressure would vary sharply and born shock wave [8,9]. From LongGold-Christine Yu relationships it can be get that the change situation of the shock wave generated before and after, with which gas pressure ratio, temperature and density ratio[10]. When the target fly at high speed, the shock wave brought would change sharply with temperature, pressure and density of surrounding gas. And the change of air pressure would affect acoustic pressure to change. Thus we could get the change of air pressure by measuring the change in sound pressure, and would get the signal of acoustic detection array passed by the target [11].

When acoustic pressure changing, the acoustic pressure would propagate at a certain speed. The change of acoustic pressure is related with the speed of target fly, the density and temperature of surrounding gas. In a small space the target with high speed velocity changes very little, it can be the considered approximately constant of the impact between the speed change of the target flying to the propagation velocity of sound pressure, and the air temperature and can pressure can be considered constant. The paper is based on the principle of time delay test theory. For the detector array’s structure is designed small, the distance between the probe cells are controlled in a small area relative to the sound pressure propagation velocity, it can be ignored the measurement error caused by the acoustic pressure propagation velocity, the acoustic pressure in a very short distance propagates at a constant velocity.

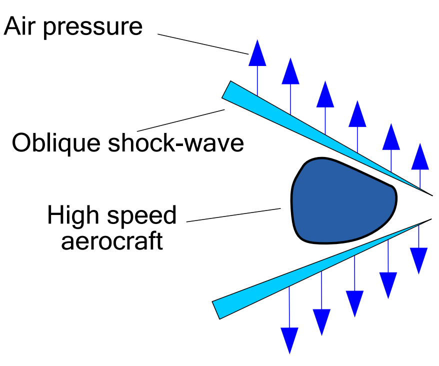


Figure 1. Shock-Wave Signal

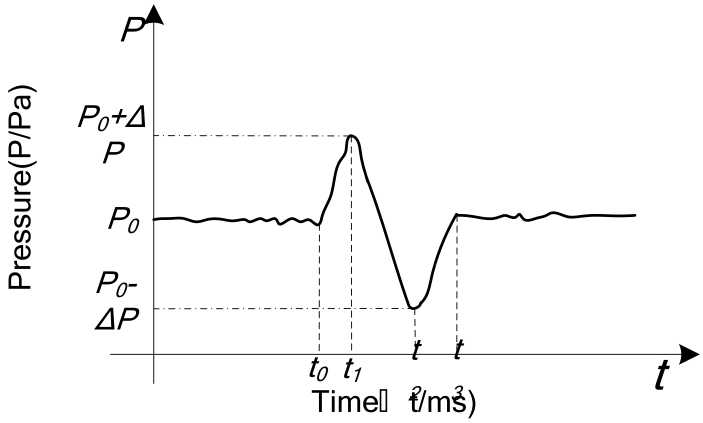


Figure 2. Change Figure of Acoustic Pressure

When the target flys at high speed, the shock wave is born, and the schematic diagram is as Figure 1 shown. The shock wave generated by the target flying would affect the surrounding air pressure to change, the direction of air pressure changes is perpendicular to the bullet propagation direction, the change in air pressure reflects ultimately in the changes of sound pressure and sound field [12]. When sound pressure detection equipment is laid below perpendicularly under the bullet trajectory, the equipment would get sound pressure change information when the target passing, so he target parameters can be test [13]. As Figure 2, when there is no target passing through, the acoustic sound pressure is P0. When the target fly at supersonic speed, owing to the passing target the air would sharply compressed and the air pressure would increase, at time t0 the change of sound pressure spreads to the detector, at time t1 it reaches the maximum, then the air pressure reduces, at time t2 it reduces to the minimum, next it restores gradually again, at time t3 it returns to steady state. Accordingly the output signal of the sound pressure detector would detect the change of sound pressure, output electrical signal, that the trend of electrical signal is consistent with the sound pressure information. Finally, by means of the signal processing, it can obtain related information of the target.

3. Mathematics Model for Acoustic Array of Target Information Measurement

Single point test is not able to accurately calculate parameter information when the target passing, the paper adopts three plane geometry to compute parameter information. As shown in Figure 3, when a target at high speed fly through two measure plane with regular triangles

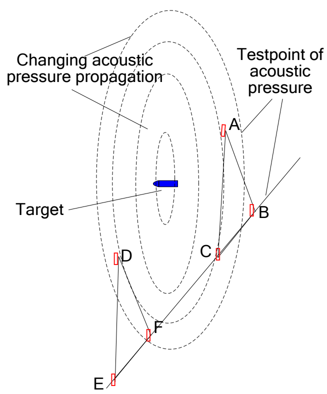


Figure 3. Testing Principle of High Speed Aero Craft

array, the shock wave changes by the target, that results air pressure to change in vertical of fly direction. The air pressure changes in the origin of target and diffuses around, that forms air pressure with a round face shape to communicate. Due to the presence of the interval between the detection elements, each detection element would receive the change of air pressure information in different time, in which points *A*,*B* and *C* form a test array of regular triangle, three points are laid three detecting units respectively, points *D*, *E* and *F* form another test array of regular triangle.

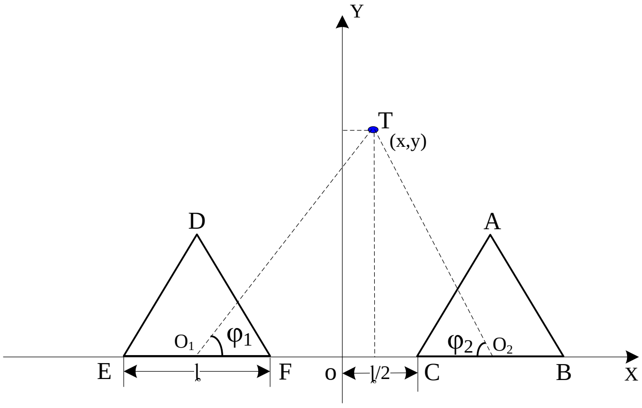


Figure 4. Geometry Relationship of Target Coordinate

The Figure 4 is test schematic diagram of high speed target with the Figure 3, the side length of regular triangle test network is l in test network, the two regular triangles are symmetrical *Y* axis, two sides *EF*, *BC* in regular triangle coincide *X* axes, the distance between point *B* and the origin is $l/2$, O_1 and O_2 are the centrality of the two sides respectively. When target passing through, intersection angle between the target and O_1,O_2 are φ_1, φ_2 respectively, all of this can get by geometry

$$x = l \times ((\tan\varphi_1 - \tan\varphi_2)/(\tan\varphi_1 + \tan\varphi_2)) \tag{1}$$

$$y = \sqrt{3}l/6 + 2l \times ((\tan\varphi_1 \times \tan\varphi_2)/(\tan\varphi_1 + \tan\varphi_2)) \tag{2}$$

In formula (1) and (2) there is $\varphi_1, \varphi_2 \in (0, \pi/2)$。

From above-mentioned it is no longer to depend on sound velocity value to solve parameter information of the target position. The method would effectively improve the solution precision of target parameters. It transforms to calculate the angle between intersection target and two probe array center to solve the parameter information problem. Thereby it can calculate intersection angle between target and test array centrality, and get parameter information of target.

When the target pass through the test array, the shock waves born would cause acoustic pressure change and transmission process, As Figure 5, the arrowhead indicates transmission procedure of the acoustic pressure change. Suppose time delay spreading from *A* to *C* is t_{AC} and time delay spreading from *A* to *B* is t_{AB}, the transmission speed of acoustic pressure is V_C,, then

$$t_{AC} = AG/V_C \tag{3}$$

$$t_{AB} = AH/V_C \tag{4}$$

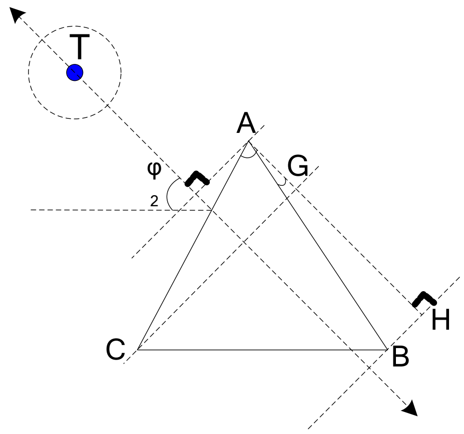


Figure 5. Geometry Graph of Intersection Angle

The intersection angle is φ_2 between the propagate direction of acoustic pressure with horizontal direction, then

$$\begin{aligned} AC &= l \times \cos(120^\circ - \varphi_2) \\ &= l/2 \times (\sin\varphi_2 - \sqrt{3}\cos\varphi_2) \end{aligned} \tag{5}$$

$$\begin{aligned} AH &= l \times \cos(60^\circ - \varphi_2) \\ &= l/2 \times (\sqrt{3}\sin\varphi_2 - \cos\varphi_2) \end{aligned} \tag{6}$$

Combined the formulas above, there is

$$\tan\varphi_2 = \frac{\sqrt{3}}{3} \times \frac{t_{AB} + t_{AC}}{t_{AB} - t_{AC}} \tag{7}$$

Similarly, when the target passing through test array, the intersection angle relationship between the target with test array of regular triangle *DEF*.

$$\tan\varphi_1 = \frac{\sqrt{3}}{3} \times \frac{t_{DE} + t_{DF}}{t_{DE} - t_{DF}} \tag{8}$$

From the expression with (1), (2), (7) and (8), we can get the parameter information when the target pass through detection structure of acoustic array.

$$x = l \times \frac{(t_{DE} - t_{DF}) \times (t_{AB} + t_{AC}) - (t_{DE} + t_{DF}) \times (t_{AB} - t_{AC})}{(t_{DE} - t_{DF}) \times (t_{AB} + t_{AC}) + (t_{DE} + t_{DF}) \times (t_{AB} - t_{AC})} \tag{9}$$

$$y = \frac{\sqrt{3}}{6} l + \frac{2l}{3} \times \frac{(t_{AB} + t_{AC}) \times (t_{AB} - t_{AC})}{(t_{DE} - t_{DF}) \times (t_{AB} + t_{AC}) + (t_{DE} + t_{DF}) \times (t_{AB} - t_{AC})} \tag{10}$$

4. Characteristic of Acoustic Pressure in Target

When there’s a single target passing through the sound pressure array, the target can be effectively recognized from the acoustic array structure designed. Traditionally to use threshold voltage method can’t be effectively distinguish of multiple targets. Because when there are multiple targets, the detection circuit would output analog signal to increase strength, the target signal would exceeds the threshold voltage, which can just identify whether there’s a signal or not, and can not carry out analysis effectively to multiple targets signal and can not get the feature of the target signals, that it’s unable to process interference signal [14,15]. For a certain target acoustic pressure signal, it would be analyzed in frequency domain that it is superimposed of some different amplitude and frequency signal, shown as following:

$$w(f) = A_1 H(f_1) + A_2 H(f_2) + \cdots A_n H(f_n) \tag{11}$$

Thereinto *w(f)* is analogy signal expression of sound pressure when the target passing through the test array, the sound signal can be transformed to frequency $f_1, f_2 \cdots f_n$ by the way of time-frequency method, and the corresponding amplitude are $A_1, A_2 \cdots A_n$, accordingly the acoustic pressure signal can be can analyzed from time domain to frequency domain.

When there are sound pressure signals born from multiple targets, it can get the expression,

$$\begin{bmatrix} w_1(f) \\ w_2(f) \\ \vdots \\ w_N(f) \end{bmatrix} = \begin{bmatrix} A_1^1 & A_1^2 & \cdots & A_1^n \\ A_2^1 & A_2^2 & \cdots & A_2^n \\ \cdots & \cdots & \cdots & \cdots \\ A_N^1 & A_N^2 & \cdots & A_N^n \end{bmatrix} \bullet \begin{bmatrix} H(f_1) \\ H(f_2) \\ \vdots \\ H(f_n) \end{bmatrix} \tag{12}$$

Thereinto $w_i(f)$ indicates number of i sound pressure signals exiting, other parameters are same meaning with expression (9). Therefore it can obtain acoustic pressure signal characteristics of multi targets, by which analyze amplitude-frequency characteristics of the target acoustic pressure signal.

5. Error Analyze of Testing

From the mathematical expressions of the target location, it can be conducted that the main factors affecting measure accuracy are detecting element spacing in regular triangle array, spreading of acoustic pressure and delay time of each detector element. From the expression it can be known that the effect of testing accuracy is fixed when detecting element spacing is stable. In theory when the target passing through the test array, there is a very large space during each test, as long as $\varphi_1, \varphi_2 \in (0, \pi/2)$ there would achieve the testing conditions. But in such big test space not all the test points can realize high accuracy test to the target position information. Within the range of test space may get the high precision of measurement accuracy. In certain circumstances with the detection array structure, it analyzes the elements of affecting the test precision, and get the expression of the target coordinate information based on the error analysis theory.

$$\delta_x = \delta_0 \times \sqrt{2}l \frac{\sqrt{\sec^8 \varphi_1 \tan^2 \varphi_2 + \sec^8 \varphi_2 \tan^2 \varphi_1}}{(\tan\varphi_1 + \tan\varphi_2)^2} \tag{13}$$

$$\delta_y = \delta_0 \times 2\sqrt{2}l \frac{\sqrt{\sec^4 \varphi_1 \tan^2 \varphi_2 + \sec^4 \varphi_2 \tan^2 \varphi_1}}{(\tan\varphi_1 + \tan\varphi_2)^2} \tag{14}$$

Thereinto δ_0 is inherent system error relating to the overall performance of the system. In order to get the influence test error accuracy by two intersection angles, expression (11) and (12) is simulated by MATLAB, so the influence can be get of the two intersection angles relating to measurement accuracy.

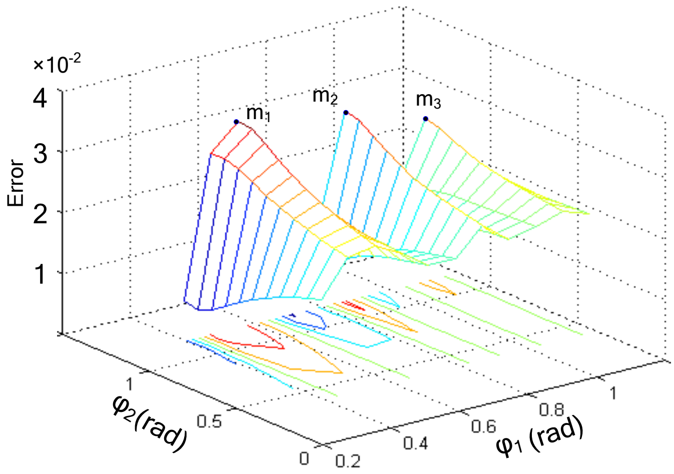


Figure 6. The Influence of Testing Accuracy of Intersection Angle between φ_1 , φ_2 and X Coordinate Precision

From the Figure 6, the impact is different that the two intersection angles influence test precision in X axis. As shown in Figure m_1,m_2 and m_3, the three points are the extreme points in error precision. If φ_1 is fixed, the test precision would be lager according to φ_2 increasing. The effect is not a linear relationship of two intersection angles acting to X axis coordinate precision, the error fluctuates markedly. Therefore in order to reduce the error precision in X coordinate test, the values of φ_2 should be smaller, while the values of φ_1 should be larger, which can benefit increasing test precision in x coordinate.

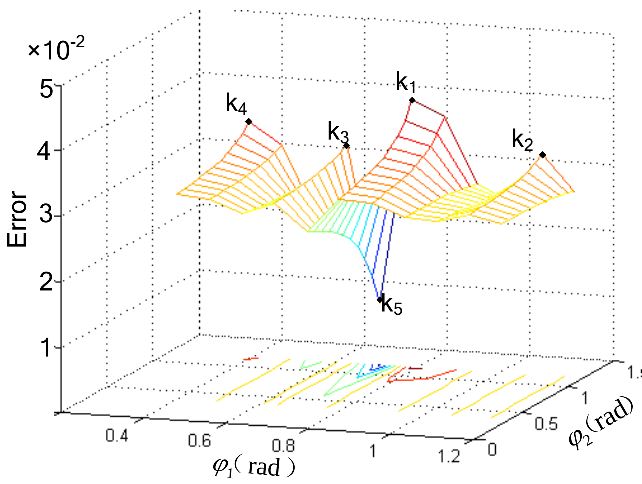


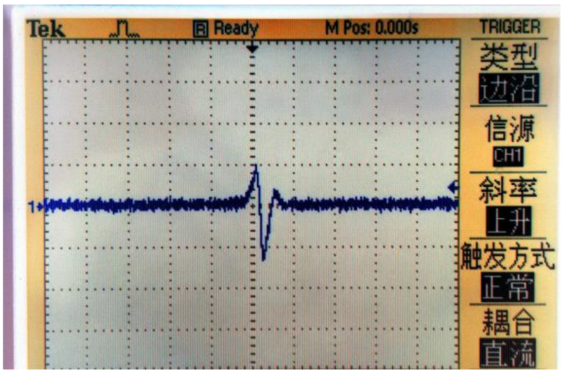
Figure 7. The Influence of Testing Accuracy of Intersection Angle Between φ_1 , φ_2 and Y Coordinate

From the Figure 7, it would result in some maximum and minmum value points that the two intersection angles influence to test precision in Y axis coordinate. Generally the smaller the φ_2 is, the lager the error precision is in Y axis. It can be seen from the Figure that with the increasing that φ_1 is, the test error accuracy in Y axis coordinates tends to stable and the error fluctuation decreases, all of this are helpful to enhance test the stability and improve the test precision.

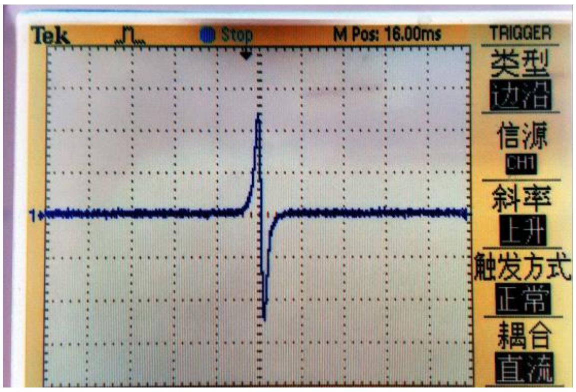
By analysis the influence of error accuacy from *X* coordinate and *Y* coordinate, it can be learned that reduce of φ_2 and the increase of φ_1 are beneficial to test target position information of high-speed fly, and improve measurement error precision in *X* coordinate and *Y* coordinate. Because the two angles are symmetrical on target, if only the two probe array angles have obvious difference when target flying across the detector array with in the test, namely φ_1 large and φ_2 small, or φ_1 small and φ_2 large, these are all helpful to improve the error accuracy of test target.

6. Experiment and Simulation

In order to verify the theorey analysis above, a test platform is build, waveforms is get, as shown in Figure 8. Figure 8(a) is the waveform changes of single target through, the variety of waveform changes agreed with the theoretical analysis, Figure 8(b) is the waveform changes when two targets through, the signal strength is bigger than single.



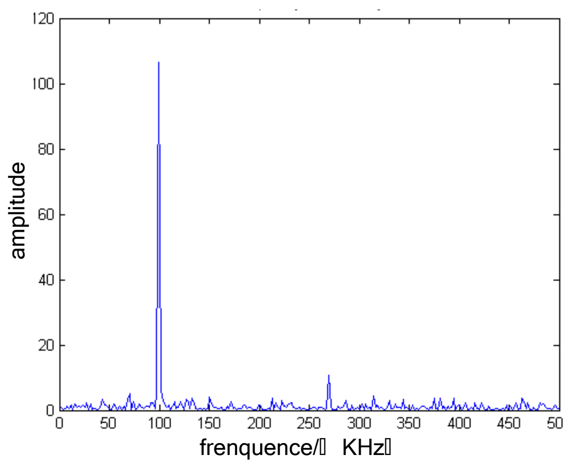
(a). Single target signal



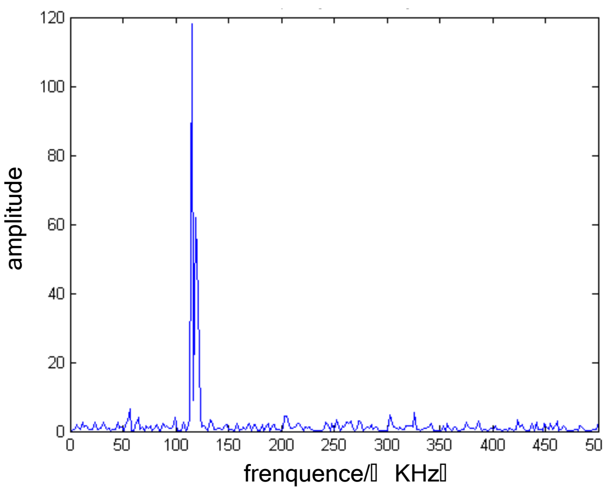
(b). Multiple target signal

Figure 8. Analogy Signal Wave of Target

To transform the two signals into frequency domain, the signal characteristics of the target can get in frequency, as shown in figure 9.



(a). Spectrum conversion diagram of single target signal



(b). Spectrum conversion diagram of multi target signal

Figure 9. Transformation Diagram of Signal Frequency Domain

Figure 9(a) is the frequency domain transformation graph of single target, which corresponds to Figure 8(a). As the Figure 9(a), when target through detection array, the frequency of detection array is 100KHz , in 250~300KHz there is a high frequency but small amplitude signal, which is a random interference signal, and it would not affect the signal characteristic analysis. Corresponding to Figure 8(b), Figure 9(b) is spectrum transformation graph of multiple targets, there are two frequency signals beyond 100KHz, one is strong, the other is weak. If the same two targets pass through, the array structure would interact in the sound pressure, but on the whole the signal intensity would bigger than single target, besides the mutual influence by each other the effect generated is not just a simple superposition of single signal. In this experiment it performs target signal frequency to increase a little.

7. Conclusion

During the analysis of the sound pressure detecting principle, an acoustic array test structure is designed with regularl triangle, and a mathematical expression is obtained to calculate the target parameter information of acoustic array. It can drive that target coordinate position is independent of the acoustic velocity spread by analysis the mathematical model. This opinion changes the previous acoustic array testing method based on acoustic wave propagation velocity. In order to obtain the target information better, we use the method of time-frequency conversion to anaylyze collect signal, and obtain signal characteristics to acoustic array test environment of single target and multiple targets, and analyze the test accuracy influence of two angles by simulation experiment, get the method to improve testing precision. The study lays a certain foundation to research multiple target signal testing under the acoustic array testing environment, as well as it has some guiding significance for practice.

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