

Array model of shock pressure sensor for shooting point detection

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Abstract. The array model of double-T shock pressure sensor is established. Shock wave is produced by a supersonic object in the air. Pressure is produced in the process of shock wave transmission. Different shock pressure sensors have different time to receive the pressure signal. In this paper, the shooting point calculation model and the finite element model of the double T-shaped array method are established. The simulation experiment is carried out. The law of shock wave propagation is verified. The model can be used to calculate the coordinates of shooting point quickly. This method is suitable for small angle oblique fire location problem, and improves the detection accuracy of shooting point.

Keywords: Target surface, Shock pressure sensor, Acoustic positioning, Double T-type.

1 Introduction

In order to improve the efficiency of training, it is necessary to detect the coordinates of hitting target quickly and accurately in shooting competition. The detection methods of bullet hitting target surface position include coordinate target based on image processing, metal rod measuring target, linear CCD photoelectric target, photoelectric coordinate detection target and sound locating target [1-3]. Among them, the acoustic location detection technology has been widely used because of its strong adaptability to environment and convenient arrangement. The arrays of shock pressure sensor in sound positioning detection are N-point line array, L-type array, double triangle array and T-type array [4-6]. The method of sound positioning is characterized by convenient installation, strong environmental adaptability, reliable performance, small size, low cost and simple structure.

In this paper, the double-t type array model and mathematical model are established. The solution method of double-T model is described. The feasibility of the model is verified by simulating the shock wave produced by the bullet.

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2 Establish positioning model

In this paper, the layout model of double-T shock pressure sensor is proposed. In addition, the algorithm of the model is also proposed. The double T-type array model is composed of two single T-shaped arrays. The first single T-type array consists of Q_4, Q_5, Q_6 and Q_7 . The second single T-type array consists of Q_1, Q_2, Q_3 and Q_5 . Two single T-types array share the same shock pressure sensor Q_5 . Seven shock pressure sensors are arranged on the same level. The time difference signal detected by the shock pressure sensor of the first single T-array and the shock pressure sensor of the second single T-array are solved jointly. In this way a more accurate bullet velocity can be measured. This method can improve the accuracy of hitting point detection. It also detects the flight angle and trajectory at the end of the bullet. It has high detection accuracy for oblique projectiles.

When an object flies in the air at supersonic speed, it will produce a strong disturbance faster than the speed of sound. The air around the projectile produces compression and expansion, which forms shock wave. The change of shock pressure curve can be divided into four processes. In the first process, the shock wave generated by the supersonic flying object increases from the air pressure P_0 to $P_0 + P_1$ in a very short time τ_1 . In the second process, the pressure drops to atmospheric pressure P_0 . In the third process, the projectile flying over causes the ambient air pressure to decrease from atmospheric pressure P_0 to $P_0 - P_1$. In the fourth process, the projectile flies past the sensor and the pressure returns to atmospheric pressure P_0 . It is often called N-wave because of the "N" shape of the air pressure. The pressure signal received by the sensor is shown in figure 1, in which T_F is the width of N wave. The characteristics of double T model include the following steps. The three-dimensional space coordinate system is established, with sensor Q_2 as the origin, the direction parallel to the target plane as the X axis, the vertical direction as the Y axis, and the direction perpendicular to the target plane as the Z axis. Sensor position coordinates: $Q_1 (-L_1, 0, 0), Q_2 (0, 0, 0), Q_3 (L_1, 0, 0), Q_4 (-L_1, 0, L_2), Q_5 (0, 0, L_2), Q_6 (L_1, 0, L_2), Q_7 (0, 0, 2L_2)$. M is the location of the hit. The location of the sensor is shown in figure 2.

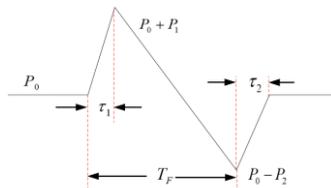


Fig. 1. N wave diagram.

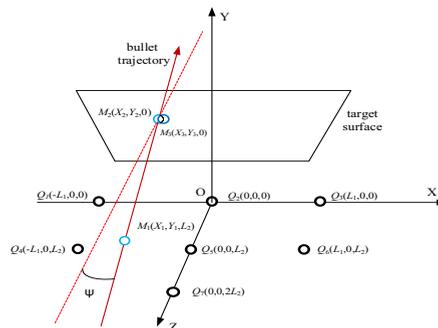


Fig. 2. Sensor position.

In shooting competition, the shock wave first reaches the first single T-shaped array. Suppose that the first coordinate point is detected as M_1 . The four shock pressure sensors Q_4 , Q_5 , Q_6 and Q_7 receive the time signals of bullets passing by, which are T_4 , T_5 , T_6 and T_7 , respectively. Suppose the coordinates of M_1 is (X_1, Y_1, L_2) . It is known that the horizontal distance between Q_4 , Q_5 and Q_6 sensors is L_1 , and the distance between Q_7 and Q_5 is L_2 . The solution equation is as follows.

$$\begin{aligned} \left[(X_1 + L_1)^2 + Y_1^2 \right]^{1/2} - (X_1^2 + Y_1^2)^{1/2} &= v_{p1} (t_4 - t_5) \\ \left[(X_1 - L_1)^2 + Y_1^2 \right]^{1/2} - (X_1^2 + Y_1^2)^{1/2} &= v_{p1} (t_6 - t_5) \end{aligned} \quad (1)$$

Bullet speed.

$$v_1 = \frac{L_2}{t_5 - t_7} \quad (2)$$

Sound velocity at ambient temperature.

$$c = 331.3 + 0.606t \quad (3)$$

Propagation velocity of shock wave.

$$v_{p1} = v_1 \tan \left(\sin^{-1} \frac{c}{v_1} \right) \quad (4)$$

According to the equations (1), (2), (3), (4), the equations are established, and the values of X_1 and Y_1 are obtained. The coordinate point M_1 detected in the first T-shaped array is (X_1, Y_1, L_2) . Then the shock wave reaches the second single T-shaped array. Suppose that the coordinate point is detected as M_2 . The time for Q_1 , Q_2 , Q_3 and Q_5 sensors to receive the pressure signal is T_1 , T_2 , T_3 and T_5 , respectively. Suppose the coordinates of M_2 is $(X_2, Y_2, 0)$. It is known that the horizontal distance between Q_1 , Q_2 and Q_3 sensors is L_1 , and the distance between Q_2 and Q_5 is L_2 . The solution equation is as follows.

$$\begin{aligned} \left[(X_2 + L_1)^2 + Y_2^2 \right]^{1/2} - (X_2^2 + Y_2^2)^{1/2} &= v_{p2} (t_1 - t_2) \\ \left[(X_2 - L_1)^2 + Y_2^2 \right]^{1/2} - (X_2^2 + Y_2^2)^{1/2} &= v_{p2} (t_3 - t_2) \end{aligned} \quad (5)$$

The speed of the bullet.

$$v_2 = \frac{L_2}{t_2 - t_5} \quad (6)$$

The velocity of the shock wave.

$$v_{p2} = v_2 \tan \left(\sin^{-1} \frac{c}{v_2} \right) \quad (7)$$

According to the equations (3), (5), (6), (7), the equations are established, and the values of X_2 and Y_2 are obtained. The coordinate point M_2 detected in the second T-shaped array is $(X_2, Y_2, 0)$. The distance between M_1 and M_2 .

$$\left[(X_1 - X_2)^2 + (Y_1 - Y_2)^2 + (L_2 - 0)^2 \right]^{1/2} = L_3 \tag{8}$$

Substitute L_3 into formula (10). The corrected velocity V_3 is obtained. In order to correct the coordinate position, V_3 is introduced into formula (11) to obtain the shock propagation velocity.

$$\begin{aligned} \left[(X_3 + L_1)^2 + Y_3^2 \right]^{1/2} - (X_3^2 + Y_3^2)^{1/2} &= v_{p3}(t_1 - t_2) \\ \left[(X_3 - L_1)^2 + Y_3^2 \right]^{1/2} - (X_3^2 + Y_3^2)^{1/2} &= v_{p3}(t_3 - t_2) \end{aligned} \tag{9}$$

The velocity of bullet after correction.

$$v_3 = \frac{L_3}{t_2 - t_5} \tag{10}$$

The velocity of shock wave after correction.

$$v_{p3} = v_3 \tan \left(\sin^{-1} \frac{C}{v_3} \right) \tag{11}$$

where: V_1, V_2 are bullet velocity, C is local sound velocity, V_{p1}, V_{p2} are shock wave propagation velocity.

According to the equations (3), (9), (10), (11), the equations are established, and the values of X_3 and Y_3 are obtained. The corrected coordinate point M_3 is $(X_3, Y_3, 0)$. The detection accuracy can be improved by this method.

3 Simulation experiment

The shock pressure sensors Q_1, Q_2, Q_3 and Q_4, Q_5, Q_6 are equally spaced in a straight line. The distance L_1 between two adjacent sensors is 10 cm. The shock pressure sensors Q_4, Q_5 and Q_6 are equally spaced in front of Q_1, Q_2 and Q_3 , respectively. Shock pressure sensor Q_7 is located in front of Q_5 . The location is shown in figure 3.

When an object moves faster than the speed of sound. The disturbance in the air cannot reach the front end of the flying body. The gas is compressed into a concentrated stream. Compressed gases produce compression and expansion. The conical shock wave formed at this time is shock wave effect. The cone shock wave is shown in figure 4.

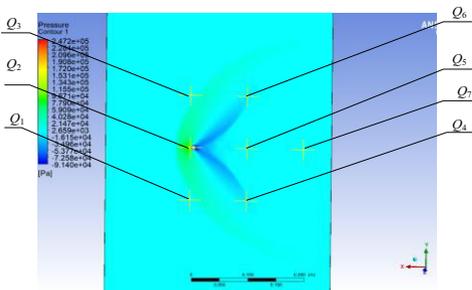


Fig. 3. sensor location diagram.

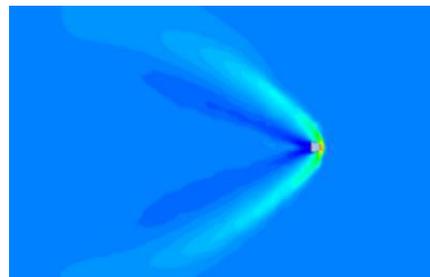


Fig. 4. conical shock.

Simulation software can be used to simulate the supersonic motion of objects in the air. The pressure signal is received by the sensor. The signals received by shock pressure sensors $Q_1, Q_2, Q_3, Q_4, Q_5, Q_6$ and Q_7 are shown in figures 5.

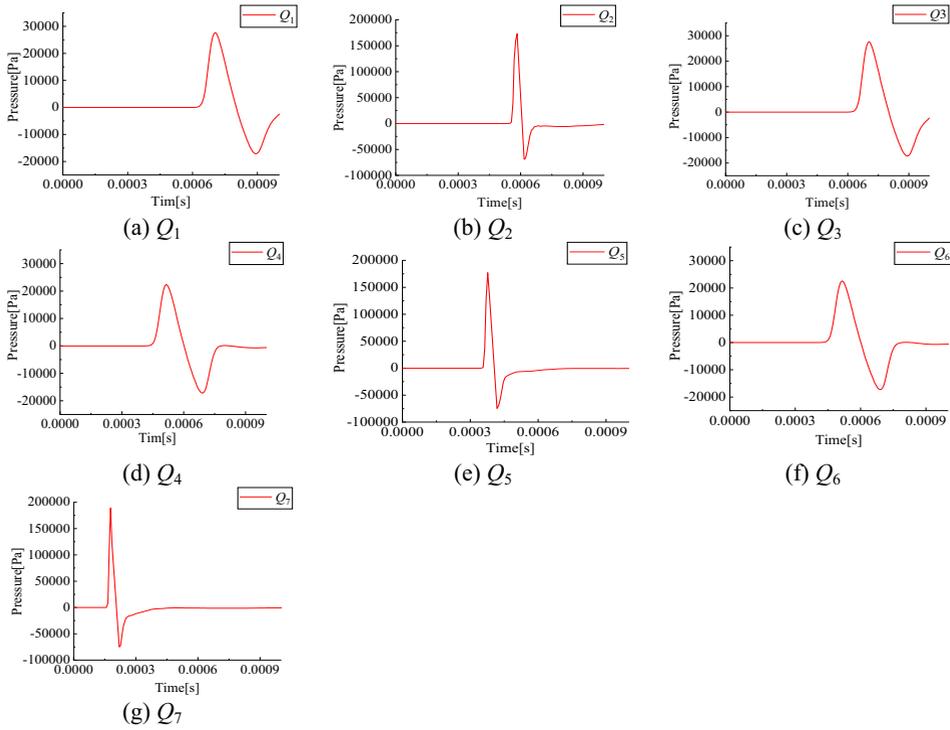


Fig. 5. Each point pressure signal.

From the above figures, it can be seen that the pressure signal received by the shock pressure sensor is in the form of "N". The time points of peaks and troughs can be obtained from the figures. The median time of N wave is taken as the time when the sensor receives the pressure signal. Table 1 shows the arrival time of pressure signal.

Table 1. Sensors position and time signals.

Sensor	Coordinate(cm)	Median time(s)
Q_1	(24,10,0)	0.000739
Q_2	(24,0,0)	0.000593
Q_3	(24,-10,0)	0.000740
Q_4	(14,10,0)	0.000500
Q_5	(14,0,0)	0.000346
Q_6	(14,-10,0)	0.000499
Q_7	(4,0,0)	0.000093

4 Conclusions

Based on the traditional N-line array. In this paper, the structure of double T-type array method is adopted. The mathematical model of target reporting system is obtained.

By analysing the movement of objects in the air. The N-wave diagram of the sensor is obtained. The arrival time of N wave is obtained by the sensors. There will be a pitch angle when shooting at an oblique angle. The shooting angle can also be calculated on the basis

of the double T-type mathematical model. Due to the limited space, this paper does not give the solution of oblique fire. It will be introduced in another article.

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