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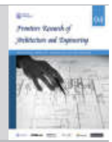

ARTICLE

Study on Correlation Characteristics of Static and Dynamic Explosion Temperature Fields

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ABSTRACT

The warheads such as missiles and artillery shells have a certain speed of motion during the explosion. Therefore, it is more practical to study the explosion damage of ammunition under motion. The different speeds of the projectiles have a certain influence on the temperature field generated by the explosion. In this paper, AUTODYN is used to simulate the process of projectile dynamic explosion. In the experiment, the TNT spherical bare charges with the TNT equivalent of 9.53kg and the projectile attack speed of 0,421,675,1020m/s were simulated in the infinite air domain. The temperature field temperature peaks and temperature decay laws at different charge rates and the multi-function regression fitting method were used to quantitatively study the functional relationship between the temperature and peak temperature correlation calculations of static and dynamic explosion temperature fields. The results show that the temperature distribution of the dynamic explosion temperature field is affected by the velocity of the charge, and the temperature distribution of the temperature field is different with the change of the charge velocity. Through the analysis and fitting of the simulation data, the temperature calculation formula of the static and dynamic explosion temperature field is obtained, which can better establish the relationship between the temperature peak of the static and dynamic explosion temperature field and various influencing factors, and use this function. Relational calculations can yield better results and meet the accuracy requirements of actual tests.

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1. Introduction

In actual combat, the warhead's attack on the target is a dynamic process. The damage effect is affected by many factors. It is necessary to combine the warhead flight speed, attack attitude, landing point and other parameters, and fully consider the coupling of the damage element to the ground or target[1], find the damage element involved in the dynamic explosion damage process, and establish the corresponding damage power evaluation index to measure the distribution of the dynamic damage power field of the warhead. Designing and using more concerned issues is more practical.

In the process of evaluating the damage power of the explosion field, the temperature of the explosion fireball is an important indicator. At present, many universities and research institutes are conducting research on the temperature test of the explosion fireball. At present, there are two main methods for measuring the temperature of explosive fireballs: direct temperature measurement and indirect temperature measurement[2][3],but the two temperature measurement methods are affected by many factors in the actual test process and the acquired temperature data has A certain error, so for the temperature measurement of the warhead under the conditions of high temperature and high pressure and strong shock vibration, there is still no effective measurement method, and most of them are carried out by simulation[4], such as: Wu Meng based on AUTODYN value the simulation software performs one-dimensional and two-dimensional numerical simulations on the aerial explosions of traditional high-energy explosives and composite aluminum-containing explosives. The explosion temperature and the explosion fireball expansion process are obtained, and they are calculated with the calculation results of empirical formulas and the measured results of related experiments. By comparison, it is found that the two have a fairly good degree of agreement[5]; Zhang Rulin, Cheng Xudong, etc. established a numerical experimental method of explosion shock wave based on LS-DYNA software, ALE algorithm and fluid-solid coupling theory, and compared the numerical experimental results with the blasting field test. The comparison of data and empirical formula calculation results verified the effectiveness of the numerical simulation experimental technique[6]; Cheng Yuteng used numerical simulation The software AUTODYN expatiates and analyzes the action mechanism of warm-pressure explosives in limited space and the empirical calculation formula of quasi-static pressure. The results show that the numerical simulation of the shock wave curve shape, peak overpressure, impulse and quasi-static pressure is in good agreement with the test results good[7]; Jiang Haiyan, Li Zhizheng and others used the AUTODYN software to simulate the dynamic explosion shock wave field of the charge, analyzed the distribution law of the dynamic explosion shock wave field, and performed regression analysis on the data. Good engineering calculation model[8].

Under the conditions of the existing test and test technology capabilities, the static explosion fireball temperature test method is more mature than the dynamic explosion. The dynamic explosion fireball temperature test faces greater problems. To solve this problem, carry out simulation calculation of static explosion and dynamic explosion temperature field distribution, and based on this, take mature static explosion temperature field data as a reference, consider multiple factors affecting dynamic explosion temperature field, and establish static explosion temperature field Correlation model of dynamic explosion temperature field, and the distribution characteristics of dynamic explosion temperature field are studied through this correlation model.

In this paper, the effect of explosive charge on the temperature distribution of the explosion temperature field is studied by modeling and calculating the static and dynamic explosion by using the explosive mechanics simulation software AUTODYN. The temperature peak, high temperature duration and temperature decay of TNT at different speeds were analyzed. Then, the temperature peaks of the static and dynamic explosion temperature fields are analyzed and fitted to establish the correlation function between the two. The results calculated by the correlation function and the simulation results have a high degree of agreement.

2. Numerical Calculation Model

In order to accurately analyze the impact of the ammunition explosion on the temperature distribution of the temperature field, this article uses the TNT spherical naked charge in charge, and uses a two-dimensional axisymmetric design[9]. Domain environment, set the other three boundaries in the picture except the x-axis to pressure outflow. In this experiment, TNT spherical naked charge was used, so the radius of the model-filled TNT explosive can be obtained according to the calculation formula of the volume of the sphere, which is 111.8mm. Set the initiation method of TNT to be the initiation of the center point[10], so set the coordinates of the center point of the filling of TNT to (0,10000). Because the length of the model is 20m, in order to keep consistent with the layout of the measuring points in the actual test, the positions of the Gauges points are 1m, 2m, 3m, 4m, 5m, 6m, 7m, 8m, 9m, and 10m from the explosion center, Take the speed direction of the movement charge as the positive direction, arrange a row of measurement points every 30° counter clock wise, and the angle between the measurement point and the positive direction of the movement speed of the charge is expressed. The model is shown in Fig.1 below:

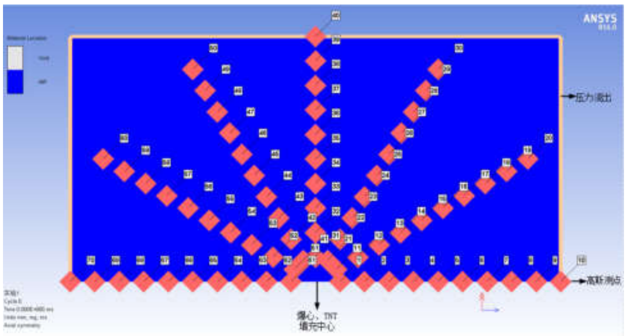

Figure 1. TNT explosion numerical simulation mode

The air in the model is an ideal gas state with a density of 0.001225g/cm; the charge is TNT, and the JWL equation of state is used. The equation is as follows[11]:

$$P = A\left(1-\frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1-\frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega}{V}E$$

In the above formula, P is pressure, V is volume, E is internal energy, A and B are material parameters, and are constants. $A = 3.712\times10^{11}$, $B = 3.23\times10^{9}\,Pa$, $R_1 = 4.15$, $R_2 = 0.95$, $\omega = 0.30$,Initial internal energy $E = 4.29\times10^{6}\,J/kg$ [12]. The square in the picture is the set Gaussian measurement point. The function of this measurement point is mainly to measure the decay curve of the

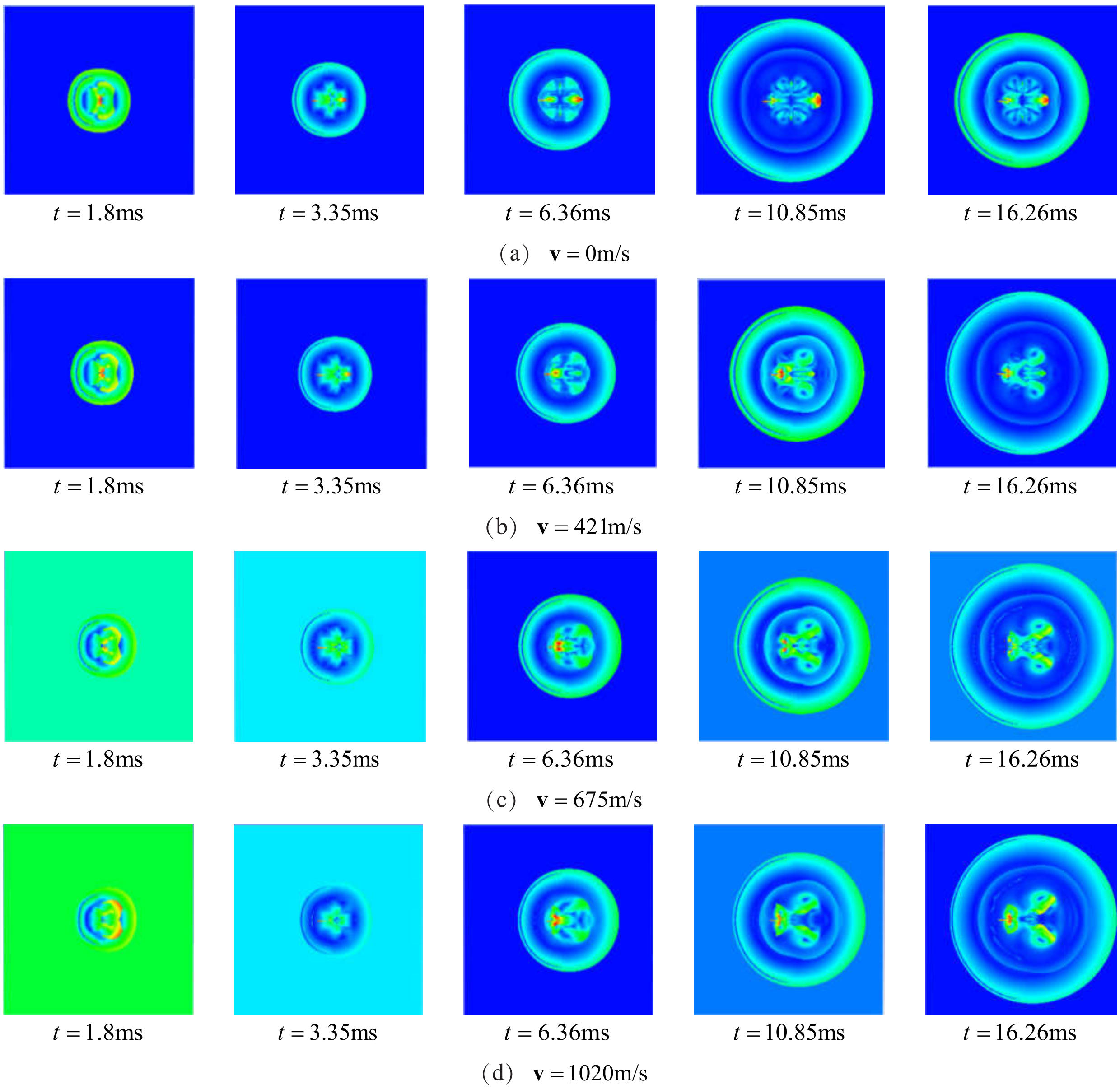

Figure 2. Temperature history of explosion temperature field at different times under 9.53kg TNT

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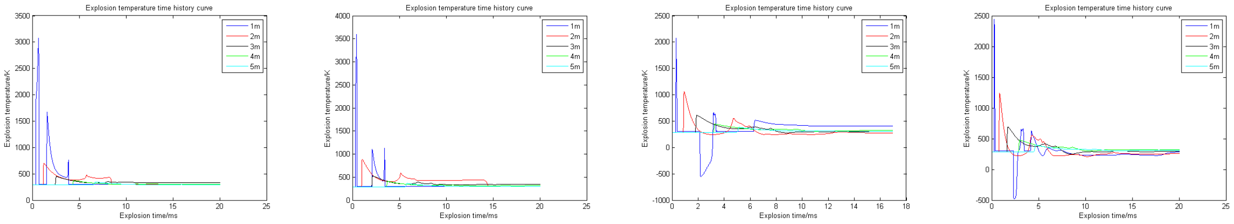
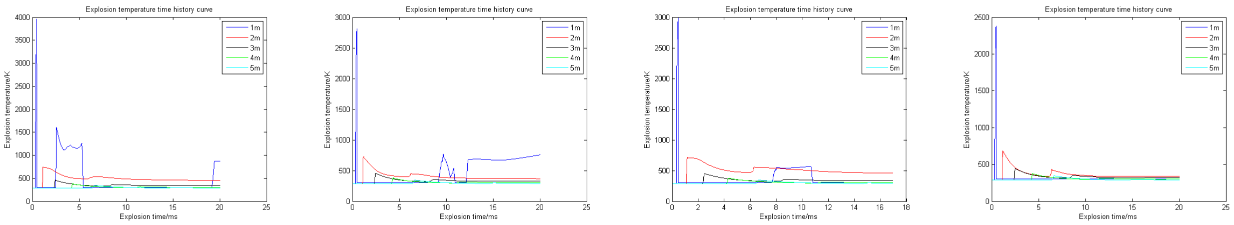


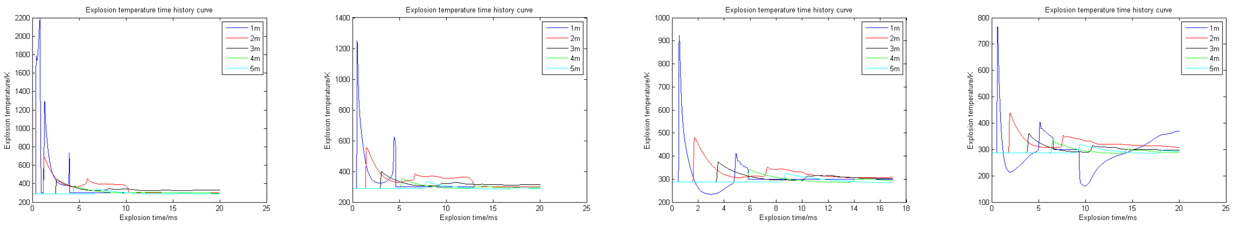
(a) $v = 0m/s$ (b) $v = 421m/s$ (c) $v = 675m/s$ (d) $v = 1020m/s$

Figure 3. 0° line explosion temperature time history curve



(a) $v = 0m/s$ (b) $v = 421m/s$ (c) $v = 675m/s$ (d) $v = 1020m/s$

Figure 4. 90° line explosion temperature time history curve



(a) $v = 0m/s$ (b) $v = 421m/s$ (c) $v = 675m/s$ (d) $v = 1020m/s$

Figure 5. 180° line explosion temperature time history curve

explosion field temperature with time during the explosion. Because the requirements for each part of the model are different, each part is also different when choosing a solver. Explosion temperature needs to be propagated in the air, so the Euler solver is used in the air. In order to ensure the accuracy of the simulation, the mesh size is divided and the material flows through the unit; TNT is a solid material, so the lagrange solver is often used for calculation[13].

3. Flow Field Evolution Analysis of Static and Dynamic Explosion Temperature Field

In this paper, the TNT equivalent is set to 9.53kg for the simulation of static and dynamic explosion. In order to study the effect of the charge motion speed on the temperature distribution of the dynamic explosion temperature field, the charge motion speeds were set to 0m/s,421m/s,675m/s, and 1020m/s during the explosion simulation. In this case, Analyze the evolution characteristics of the explosion temperature field. The simulated temperature field evolution cloud map, temperature time history curve, and temperature field central velocity versus radius change surface are shown in Fig.2, Fig.3, Fig.4 and Fig.5:

Analysis of the evolution cloud diagrams of the explosion temperature field at different moments under the different charging motion speeds can be obtained: (1) The temperature distribution of the explosion temperature field is not an equal sphere, but there are temperature differences at each stage, and the explosion The diffusion of the temperature field is very similar to that of spherical waves. (2) In the case of the charge movement speed (static explosion), the temperature of the explosion temperature field is higher near the explosion center. As the explosion time passes, the temperature high-temperature region gradually expands outward, and the temperature around the explosion center starts slowly decline, and throughout the diffusion process, each temperature layer maintains a good sphere shape to diffuse outward and evolve, so the temperature diffusion of the static explosion temperature field is a structure with x-axis and y-axis symmetry. (3) As the charge motion speed increases, the temperature field evolution cloud diagram is no longer a standard sphere. The flow field distribution is closely related to the charge motion speed, which is mainly manifested by the dynamic explosion temperature field

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moving in the positive direction of the charge motion speed In the positive direction, a local high temperature area appears, and as the temperature increases, the temperature first increases and then decreases, and when it is greater than 90°, the temperature field temperature shows a uniform decay trend. Comparing the evolution of the temperature field of the charge motion speed $\boldsymbol{v}=421\text{m/s}$, $\boldsymbol{v}=675\text{m/s}$, $\boldsymbol{v}=1020\text{m/s}$, it can be found that as the charge motion speed gradually increases, the temperature gradient of the explosion temperature field at the same distance and in different directions also increases, and the entire explosion temperature the distribution of the field is also becoming more and more uneven, and its isotherms are increasingly deviating from the circular distribution.

Read the temperature data at different measuring points of the explosion temperature field under the moving charge and analyze it, and get the change of the center velocity of the temperature field with the explosion time at different charge movement speeds. The time change curve is shown in Fig.6 and Fig.7 below:

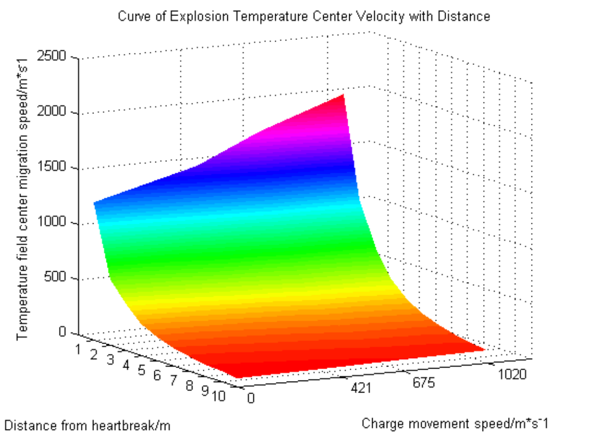


Figure 6. Surface of the change in the central velocity of the explosion temperature field with the explosion time

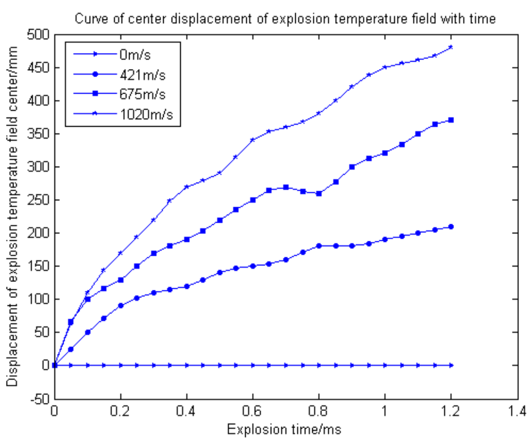
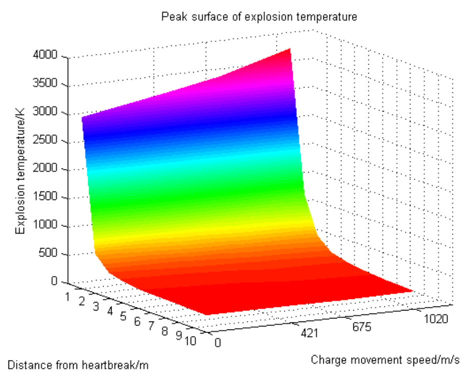


Figure 7. Curve of the center displacement of the explosion temperature field with time

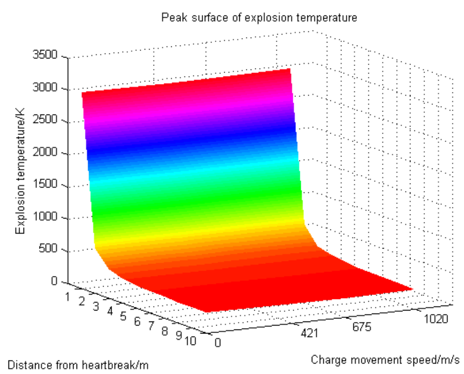
It can be seen from Fig.6 and 7 that the center moving speed and displacement of the dynamic explosion temperature field along the direction of the charging motion speed have a positive correlation with the charging motion speed, that is, the greater the charging motion speed, the greater the center moving speed of the explosive temperature field. The corresponding displacement is also greater. In the initial stage of the explosion of the sports charge, the yin deficiency of the speed of the charge, the temperature center of the explosion temperature field moves faster in the positive direction of the speed of the charge, and its displacement increases approximately linearly at this stage. As the explosion time progresses, the explosion temperature field gradually spreads outward, the center of the temperature field's moving speed gradually decreases, and the increase in its displacement also slows down. The impact gradually diminishes and eventually approaches zero.

3.1 Comparison of Temperature Peaks in Static and Dynamic Explosion Temperature Field

In order to study the impact of the charging speed on the explosion temperature field, the peak temperature of the explosion temperature field was quantitatively extracted based on the above simulation data. Curved surface to analyze the change rule of temperature with the speed of charge, as shown in Fig.8 below:



(a)0° line explosion temperature



(b)90° line explosion temperature

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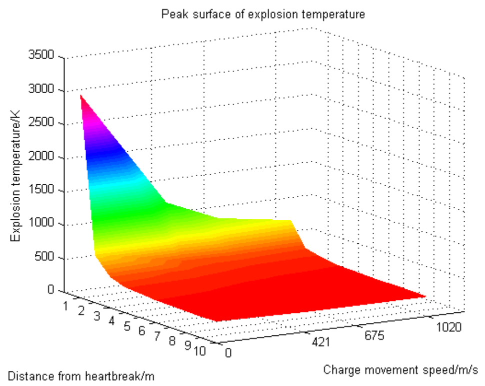


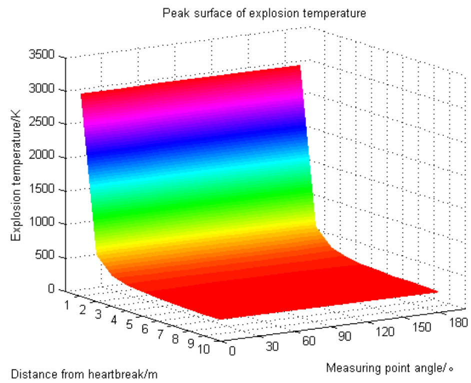
(c)180° line explosion temperature

Figure 8. Different azimuth temperature field temperature peak attenuation surface

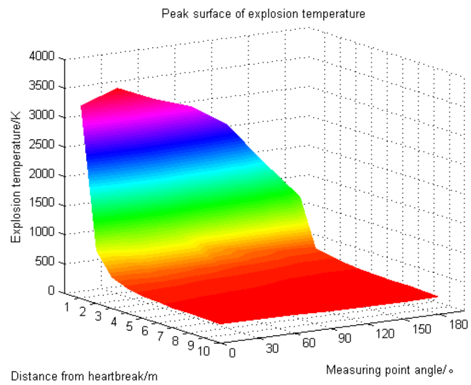
From (a) in Fig.8 above, it can be seen that as the speed of the charge increases, the explosion temperature on the 0° line increases, but the temperature change is not uniform. The main trend is that the temperature near the explosion center rises The amplitude is large, and the temperature rise in the area far from the explosion center is small. As shown in the spike rise area in the Fig.8, combined with specific data for analysis, when the speed of sports charging increases from to, the shock wave at the measurement point of 1m-5m The peak growth rates are 0.87, 0.61, 0.54, 0.27, 0.16, and the overall growth trend shows a decreasing law.

The impact of the speed of the charge on the explosion temperature field is very large, and according to the above analysis, the temperature generated by the explosion in the positive direction of the speed of the charge will increase. According to the law of conservation of energy, the explosion temperature in other directions it must also be affected by the speed of the movement of the charge. Analysis of the peak surface of the explosion temperature on the 90° survey line in (b) in Fig.4 above, it can be found that when the measurement point is 90° in the positive direction from the movement speed of the charge, the temperature peak has a smaller amplitude as the charge speed increases. In the range of 1m-5m, the maximum attenuation rate of the temperature peak at the same measuring point distance is 0.02, and the minimum attenuation rate is 0.0009. From the analysis of the peak surface of the explosion temperature on the 180° survey line in (c) in Fig.4 above, it can be seen that when the angle between the positive direction of the measurement point and the movement speed of the charge exceeds 90°, the explosion temperature no longer moves with the charge The increase in speed increases, but decreases with the increase of the charging movement speed, and the greater the charging movement speed, the faster the temperature peak attenuation rate, the maximum attenuation rate of the temperature peak at the same measuring point distance within the range of 1m-5m is 0.75, and the minimum decay rate is 0.08. And the maximum attenuation rate and the minimum attenuation rate both appear when the charge movement speed is v=1020m/s, which accords with the attenuation law of the explosion temperature field temperature.

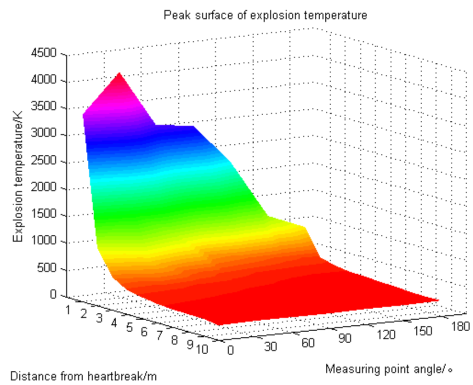
In order to analyze the peak temperature decay law of explosion temperature at different measuring points under different charging motion speeds $\boldsymbol{v} = 0\text{m/s}$, $\boldsymbol{v} = 421\text{m/s}$, $\boldsymbol{v} = 675\text{m/s}$, $\boldsymbol{v} = 1020\text{m/s}$ the temperature peaks at each measurement point are extracted and drawn into a three-dimensional surface,as shown in Fig.4 below:



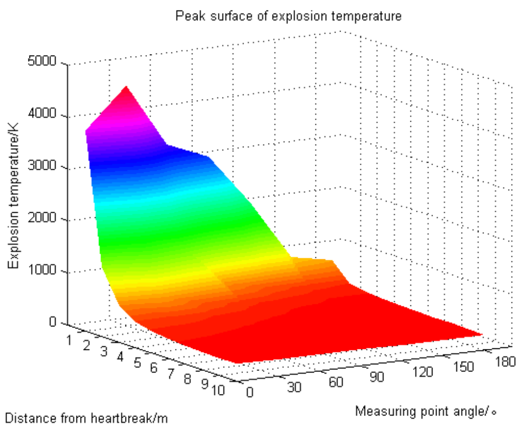
(a)0m/s explosion temperature surface



(b)421m/s explosion temperature surface



(c)675m/s explosion temperature surface



(d)1020m/s explosion temperature surface

Figure 9. Shock wave pressure peak surface at different measuring points under different loading speeds

Contrast analysis of (a) (b),(c),and (d) in Fig.9 above. Since the numerical simulation is performed in an ideal environment, the temperature evolution of the static explosion temperature field is in the form of a sphere. The outer diffusion propagates, so the peak temperature of the explosion temperature field at the same distance from the explosion center is equal, that is, the temperature of the explosion temperature field is uniformly distributed in space, as shown in (a) isotherm of Fig.4.However, with the increase of the charge movement speed, the peak temperature of the explosion temperature field at different azimuth measurement points gradually differentiates, which is mainly reflected in the temperature rise region. As the charge movement speed increases, the temperature rise also increases. In the same way, in the region where the temperature drops, the greater the speed of movement of the charge, the greater the magnitude of the temperature drop. For example, When charging speed increases from $v = 0m/s$ to $v = 1020m/s$, the maximum temperature increase peaks are 15.47%(421m/s),38.38%(675m/s),51.73%(1020m/s), and the maximum attenuation ranges are 58.85%(421m/s),69.61%(675m/s),74.80%(1020m/s), and the maximum increase ranges appear on the line 30° to the positive direction of the charging movement speed, and the maximum attenuation ranges all on a measuring line 180° to the positive direction of the charging movement speed. And according to the above analysis, the temperature of the explosion temperature field will be temperature pooled in the direction of 30° to form a local high temperature area, as shown in Fig.4(b),(c),and(d) at the azimuth of the measurement point at 30° the sharp corner area formed. Therefore, the temperature of the temperature field during the dynamic explosion process is not uniformly distributed in space, and there is a great difference in the temperature isobaric surface.

3.2 Establishing the Correlation Function of Temperature Peaks in Static and Dynamic Explosion Temperature Fields

In simple terms, the process of dynamic explosion is to add a movement speed to the charge on the basis of the static charge, so that the charge explodes during the movement, but because the speed of the charge will affect the temperature distribution of the explosion temperature field, When analyzing the temperature of the dynamic explosion temperature field, you can first use the temperature distribution of the static explosion temperature field as the basis, and then consider the impact of the charge motion speed on the temperature distribution of the dynamic explosion temperature field. The influence factor can be used to obtain the functional relationship between the temperature distribution of the static explosion temperature field and the temperature distribution of the dynamic explosion temperature field.

According to the conventional calculation method, usually the temperature peak at the dynamic explosion measurement point is subtracted from the temperature peak at the static explosion measurement point, and then the principle of controlling a single variable is used to apply a regression analysis method to each factor affecting the temperature peak of the dynamic explosion temperature field 0btain the functional relationship. The function relationship of the total static and dynamic explosion temperature field temperature peak correlation calculation is obtained by combining the functional relationships of multiple influencing factors. However, the above method considers one parameter and uses the static explosion each time. The difference between the data and dynamic explosion data, so the absolute error will increase in the calculation process, so that the final result will have great uncertainty. In order to reduce the error caused by the above, this paper uses the calculation of relative error The method to replace the absolute error is as follows(1):

$$Y = \frac{T_{dong} - T_{jing}}{T_{jing}} \tag{1}$$

In the above formula, Y is the relative error influencing factor;T_{dong} is the temperature peak of the dynamic explosion temperature field, T_{jing} is the temperature peak of the static explosion temperature field, and uses the difference between them to divide by the temperature peak of the dynamic explosion temperature field to convert the absolute error into relative error.

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After obtaining the relative error Y, the method of controlling a single variable is used to calculate the effect of the distance d at different measuring points on the relative error factor Y under the condition that the measuring point angle and the speed of the charging movement remain constant, and it is named Y_d. The temperature analysis of the explosion temperature field can be obtained. The temperature distribution of the temperature field in the dynamic explosion state needs to be divided into two parts. The forward direction area of the charging speed is part and the reverse direction area is part. According to the above calculation method, it is obtained as follows Functional relationship (2):

$$Y_d = \begin{cases} 0.0016d^3 - 0.0229d^2 + 0.0502d + 0.213 & 0^\circ \le \theta \le 90^\circ \\ 0.0007d^3 - 0.0219d^2 + 0.1973d - 0.5622 & 90^\circ \le \theta \le 180^\circ \end{cases} \tag{2}$$

Similarly,under the condition that the charging movement speed v is maintained and the measurement point distance d is maintained constant, the influence of different measurement point angles θ on the relative error factor Y is calculated, and it is named Y_θ , Get the following functional relationship (3):

$$Y_\theta = \begin{cases} -0.0005\theta^2 + 0.0169\theta + 0.2662 & 0^\circ \le \theta \le 90^\circ \\ -0.0023\theta^2 + 0.2992\theta - 12.3263 & 90^\circ \le \theta \le 180^\circ \end{cases} \tag{3}$$

Using the same method as above, with the measurement point distance d and the measurement point angle θ kept constant, calculate the effect of the charging movement speed v on the relative error influence factor Y, name it as Y_v, and get the following functional relationship (4):

$$Y_v = \begin{cases} 0.0019v - 0.0487 & 0^\circ \le \theta \le 90^\circ \\ -0.0007v - 0.0112 & 90^\circ \le \theta \le 180^\circ \end{cases} \tag{4}$$

Since the above calculations are independent calculations of the functional relationship of each influencing factor to the relative error factor Y, in order to reduce the error when integrating the three influencing factor functions, the three functions need to be added together , And then open the square root, the calculation is as shown in (5):

$$Y = \frac{T_{dong} - T_{jing}}{T_{jing}} = \frac{T_{dong}}{T_{jing}} - 1 = \sqrt{Y_d^2 + Y_\theta^2 + Y_v^2} \tag{5}$$

By converting the above functional relations, a static and dynamic explosion temperature field correlation function model can be obtained, as shown in (6) and (7):

$$T_{jing} = \frac{T_{dong}}{Y + 1} \tag{6}$$

$$T_{dong} = T_{jing} \times (Y + 1) \tag{7}$$

In order to verify the accuracy of the functional relationship to the static and dynamic explosion temperature field temperature peak fitting accuracy, the above 9.53kg static explosion temperature field temperature peak temperature simulation data was substituted into the above formula to calculate the temperature peak 5m before the dynamic explosion temperature field temperature as follows As shown in Table 1:

Table 1. 9.53kgTNT, $v = 675\mathrm{m/s}$ correlation function to calculate the dynamic explosion temperature peak table

Measuring point distance Measuring point angle	1m	2m	3m	4m	5m
0°	2254.17	1134.35	679.41	456.33	378.93
30°	5420.43	1823.56	893.22	467.12	380.63
60°	4601.02	1701.21	580.32	435.19	347.01
90°	3122.00	745.45	471.32	386.13	352.99
120°	2401.88	640.01	434.12	371.61	352.04
150°	1316.09	513.28	395.35	381.42	336.52
180°	977.12	503.06	389.54	379.73	335.98

According to the calculation results in Table 1 above, the peak value of the dynamic explosion temperature field temperature calculated using this function relationship is very close to the actual simulation peak value, and the temperature distribution and attenuation trend of the temperature field are also very close. By analyzing the above data, the maximum percentage error between the function calculation result and the actual simulation data is less than 15%. Considering the errors in the model simulation process and the system errors in the function calculation process, the functional relationship can be better It can be used in the calculation of the static and dynamic explosion temperature field temperature, which can meet the error accuracy required by the actual test.

4. Conclusion

In this paper, by using AUTODYN software to simulate the temperature of the explosion temperature field at different charge movement speeds, to obtain temperature data at different distances from the center of the explosion, and to analyze the temperature field evolution cloud map, temperature time history curve and temperature peak surface get:

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(1)There is a large difference in the temperature distribution of the static and dynamic explosion temperature field. An analysis of the evolutionary cloud map of the static and dynamic explosion temperature field shows that the static explosion temperature field presents a uniform sphere and its isotherm is distributed in a circle; while the dynamic explosion is affected by the speed of the charge, the temperature field shows an ellipsoidal distribution, so its the isotherms are distributed in an oval shape.

(2)The temperature of the explosion temperature field changes with the speed of the charge. In the dynamic explosion, with the increase of the charge movement speed, the explosion temperature migrates to the positive direction of the charge movement speed, so that the temperature in the positive direction continuously increases, while the temperature in the opposite direction continuously decreases. And the temperature peak relative decay rate is faster in the forward direction, while the temperature peak relative decay rate is slower in the reverse direction.

(3) There is a zoning phenomenon in the peak temperature change of the dynamic explosion temperature field, which is greatly affected by the angle of the measurement point. The specific performance is: in the range of 0° -90° with the positive direction of the charge motion speed, the charge speed has a positive correlation with the peak temperature increase of the explosive temperature; in the range of 90° -180° with the positive direction of the charge motion speed Within the range, the charge movement speed has a negative correlation with the peak temperature increase of the explosion temperature, and the direction that is 90° with the charge movement speed is an interface between the temperature field temperature rising region and the falling region.

(4) In the case of obtaining the temperature peak data of the static and dynamic explosion temperature field, by considering the influencing factors that affect the temperature of the dynamic explosion temperature field, a multivariate function regression analysis is used to obtain the functional relationship of the dynamic explosion temperature field temperature calculation. The relational expression can well realize the peak correlation calculation of static explosion and dynamic explosion temperature field temperature, which is of great significance in the actual explosion test.

The conclusions obtained from the above analysis of the static and dynamic explosion temperature field temperature data can provide a theoretical analysis basis for the actual shooting range test of the static and dynamic explosion temperature field distribution, and provide a test plan for the explosion temperature field test and the verification of the measured temperature field data. This new inspection method is of great significance in the actual explosion test.

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